Astrometry and Reference Frames

K.J. Johnston
U.S. Naval Observatory

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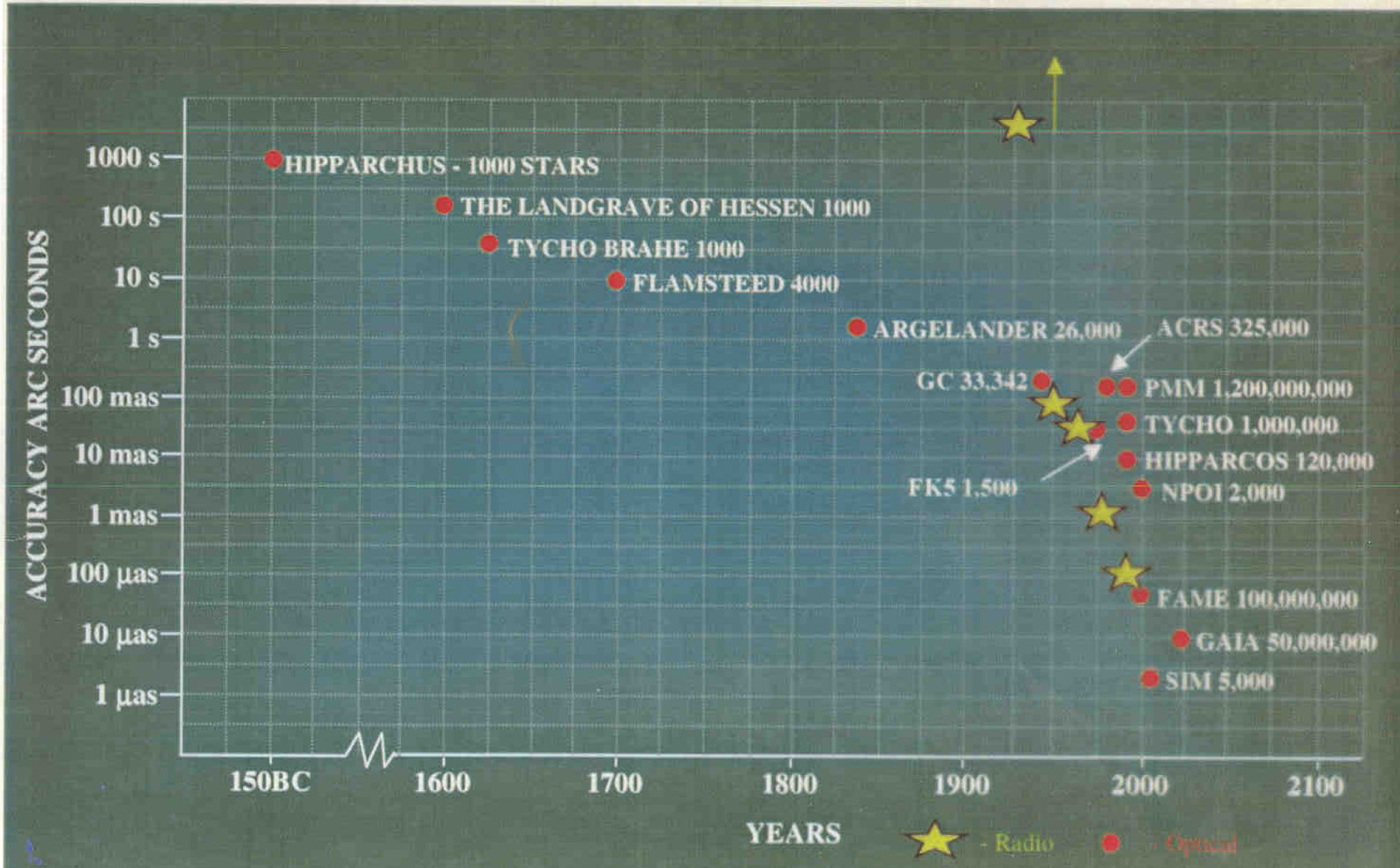
IMPROVEMENT IN ACCURACIES OF ASTROMETRIC MEASUREMENTS



International Celestial Reference System (ICRS)

- Origin - barycentric of the solar system via modeling of VLBI observations in the Frame of General Relativity
- Pole - direction defined by conventional IAU models for precession (Lieske et.al. 1977) and nutation (Seidelmann 1982)
- Origin of right ascension - fix to 3C273 (Hazard et.al 1971)FK5 value transferred to J2000
- Pole and righ ascension origin fixed relative to extragalactic radio sources to $\pm$ 20 $\overset{m}{\cancel{\mu}}$as (use Hipparcos for FK5 positions and state of art precession and nutation models)

J2000 epoch -12^h TT on Jan1, 2000

IAU 23 General Assembly, August 1997

International Celestial Reference Frame System (ICRS)

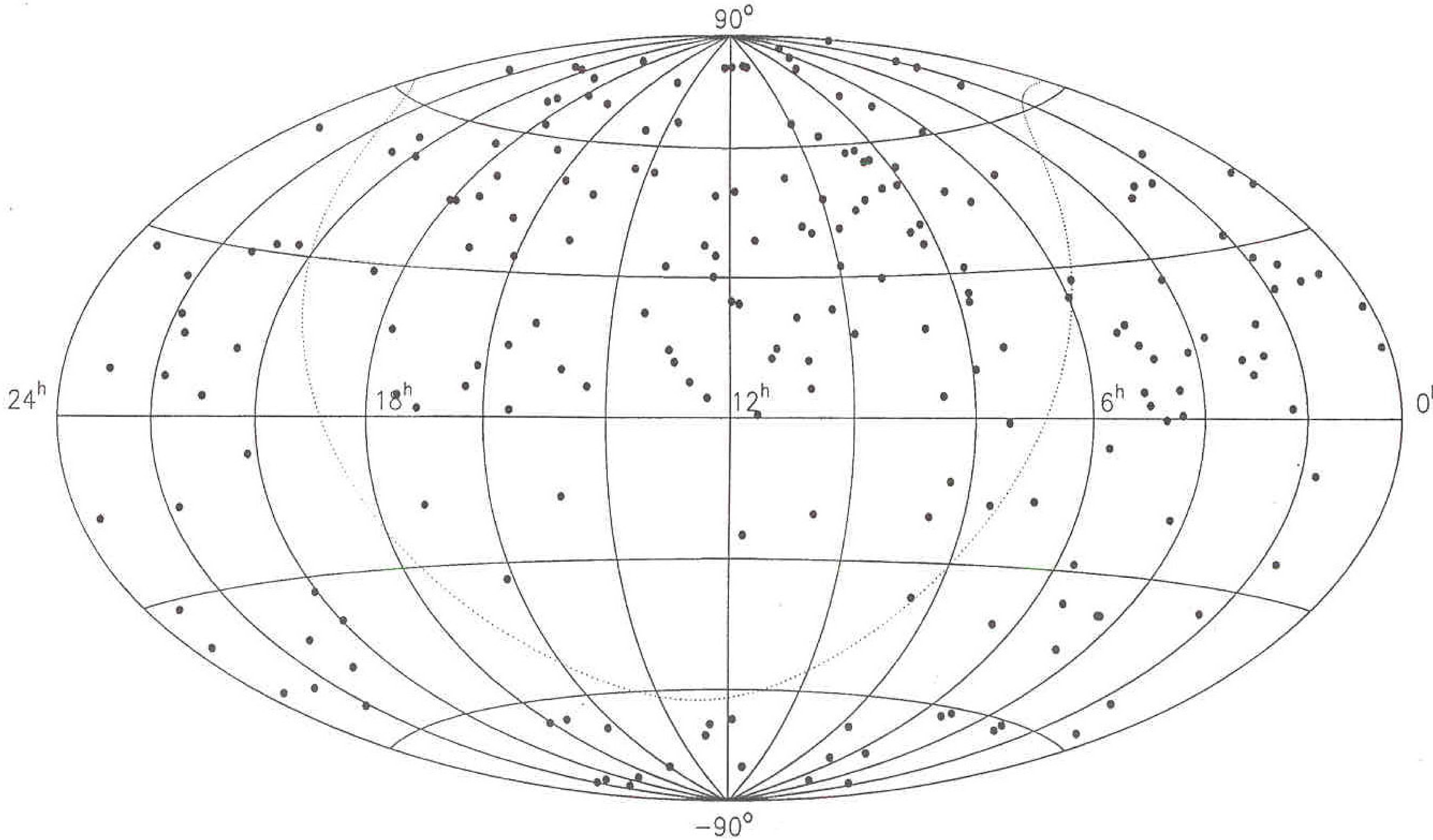
- Fiducial Points along with
- X Band Position of 212 sources (Ma et.al. 1998)

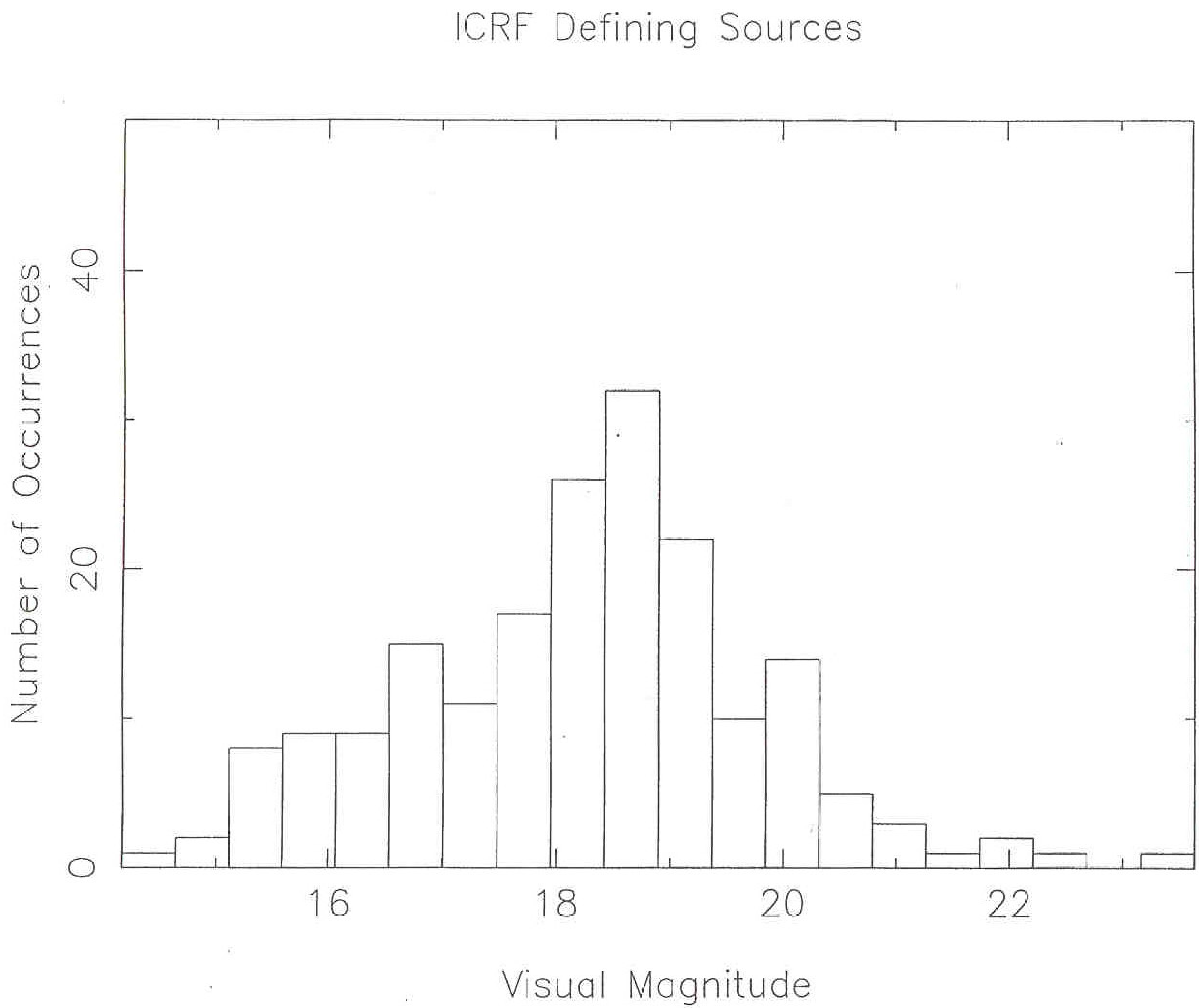
J2000

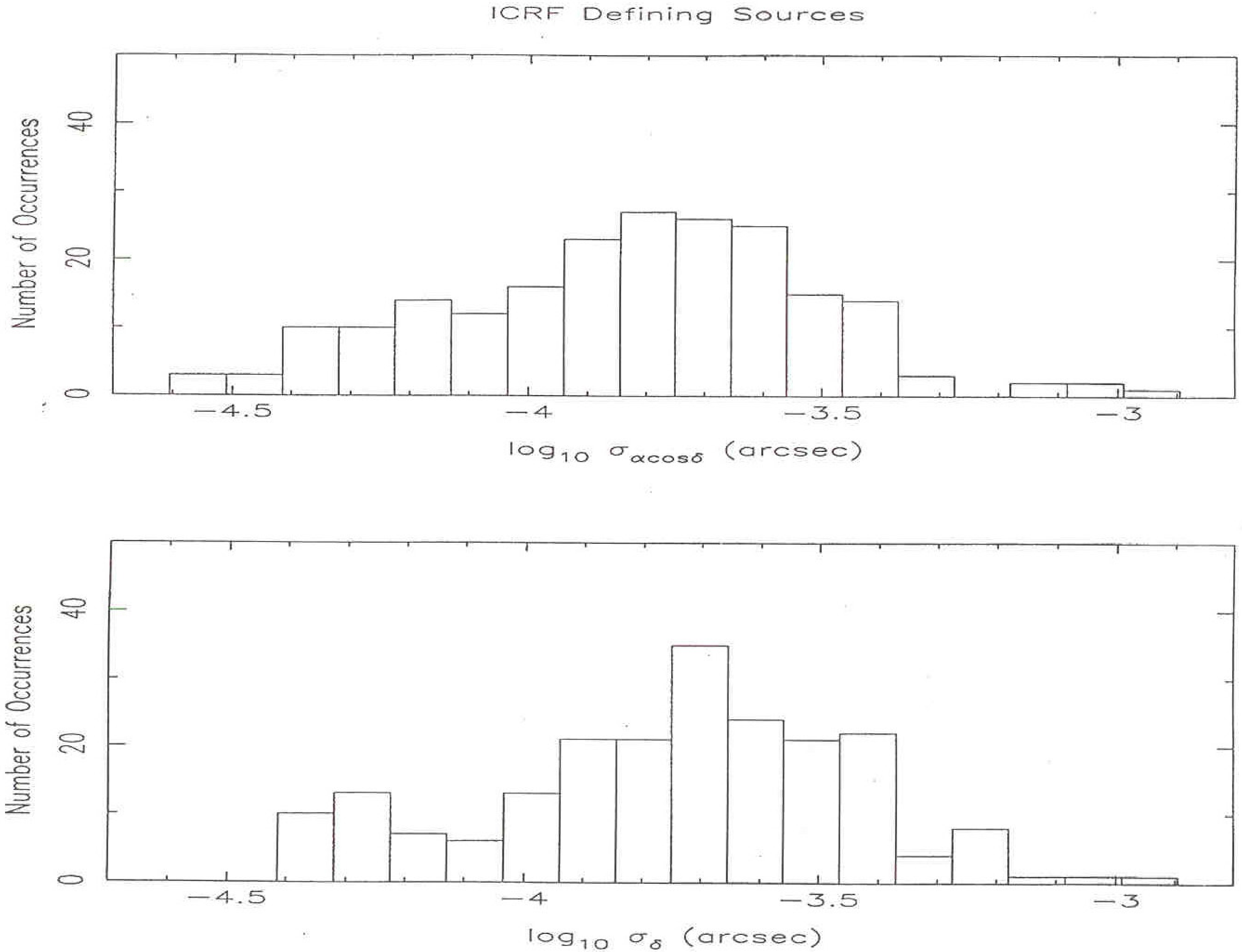
- Use Explanatory Supplement > 50 ~~μ~~mas
- Use McCarthy 1996 for < 50 ~~μ~~mas

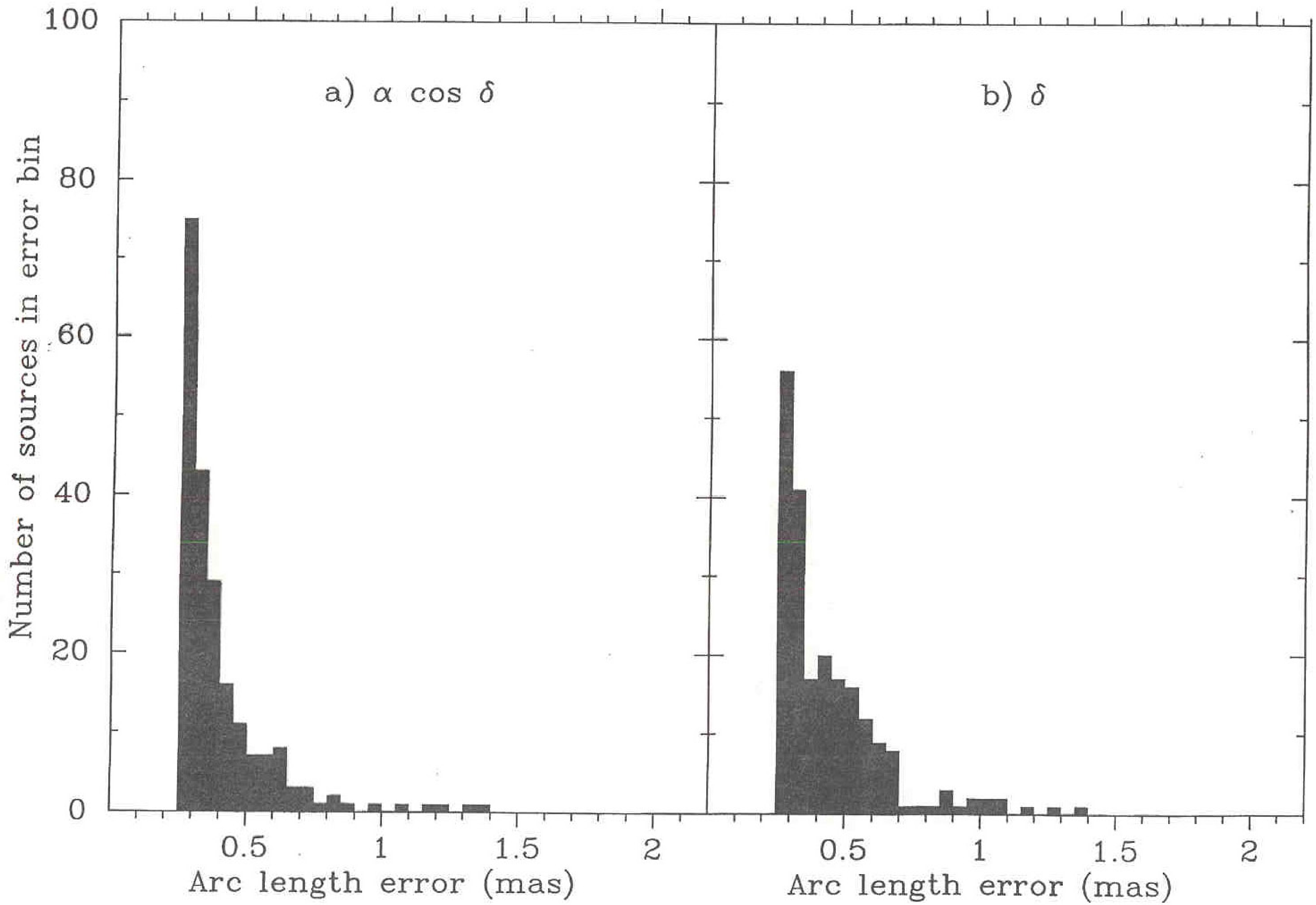
2000 IAU - New precession and nutation and other astronomical const~~r~~a~~i~~nts

The 212 ICRF Defining Sources



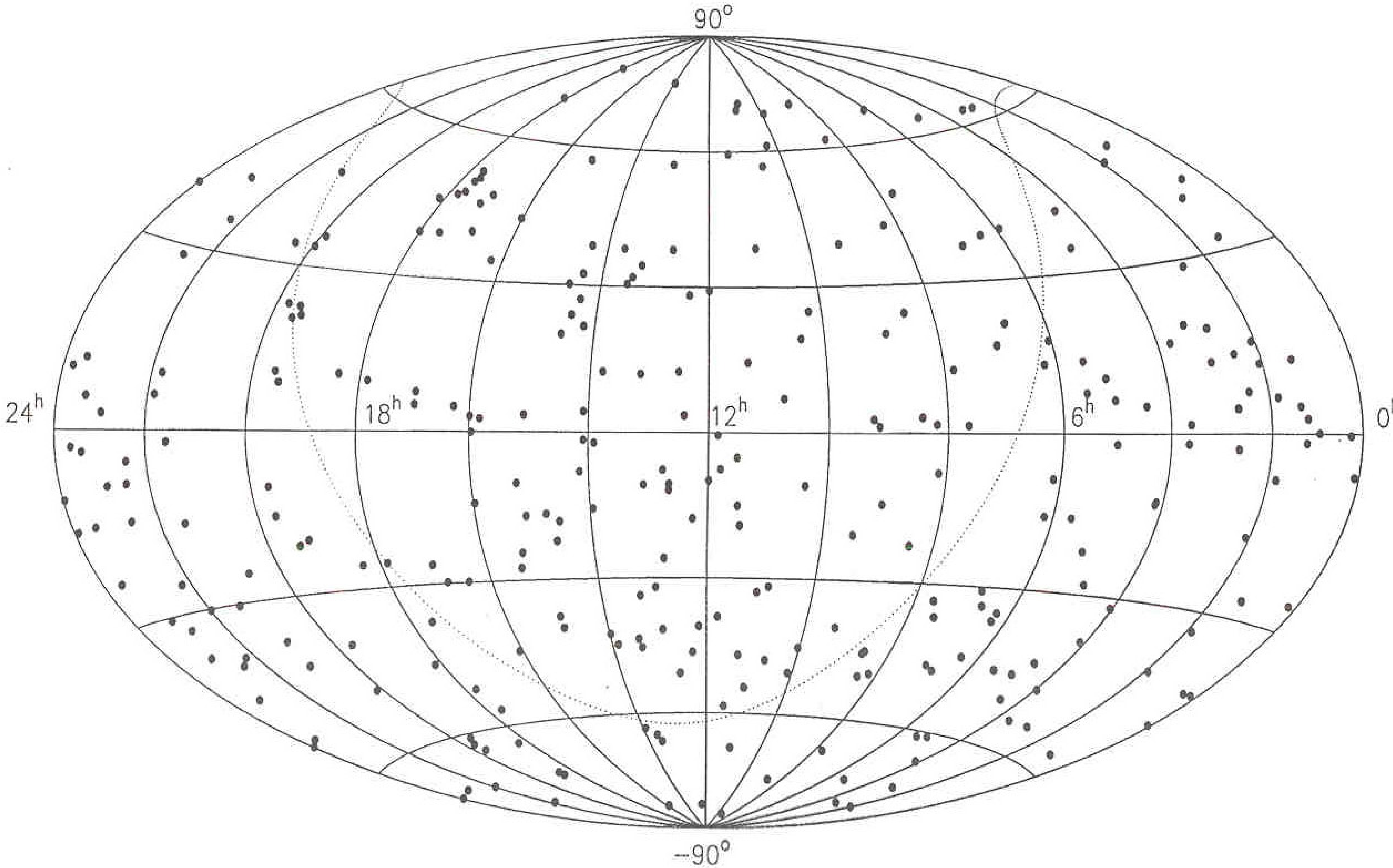

ICRF Defining Sources
Number of Occurrences
0
20
40
16
18
20
22
Visual Magnitude

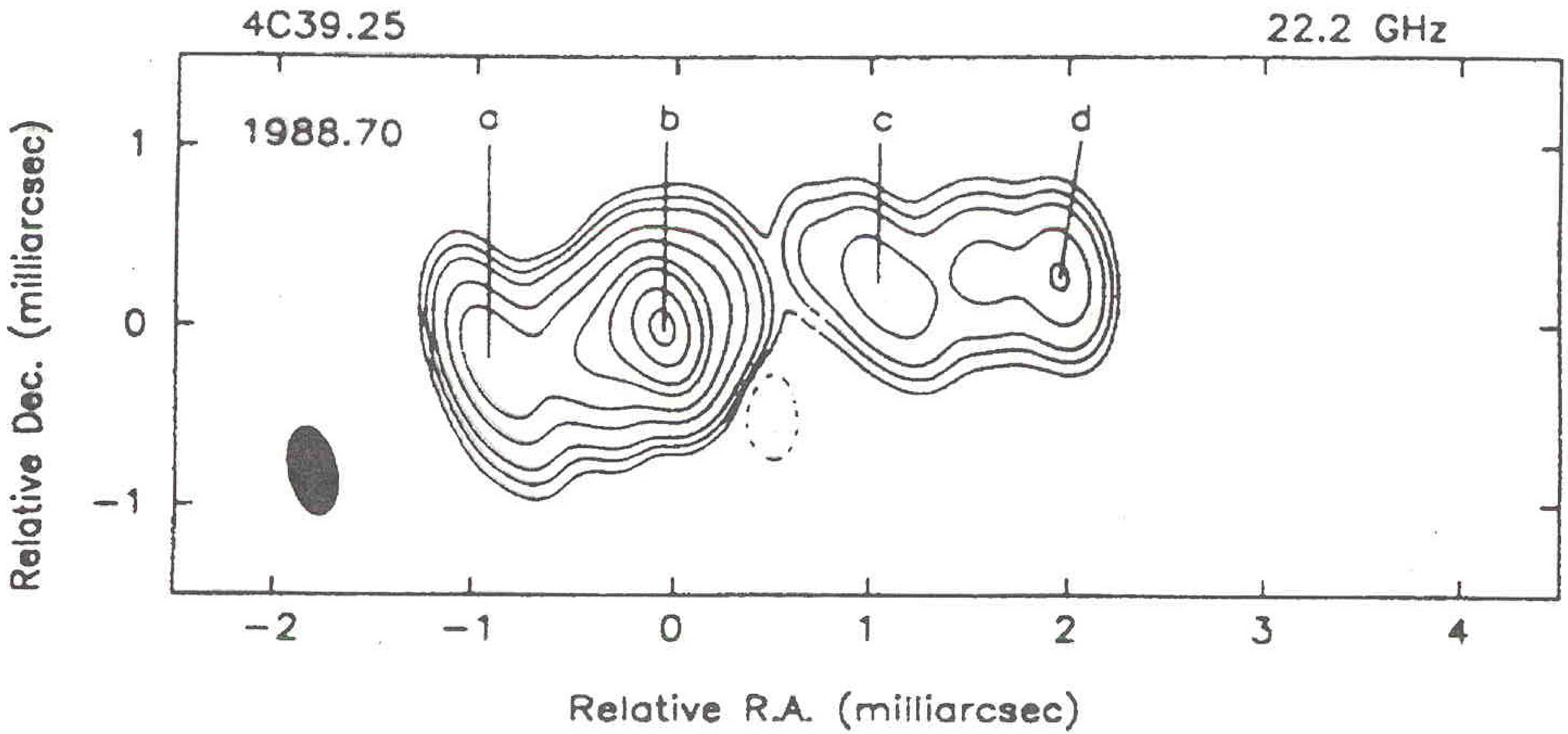

ICRF Defining Sources
Number of Occurrences
0
20
40
−4.5
−4
−3.5
−3
$\log_{10} \sigma_{\alpha\cos\delta}$ (arcsec)
Number of Occurrences
0
20
40
−4.5
−4
−3.5
−3
$\log_{10} \sigma_{\delta}$ (arcsec)



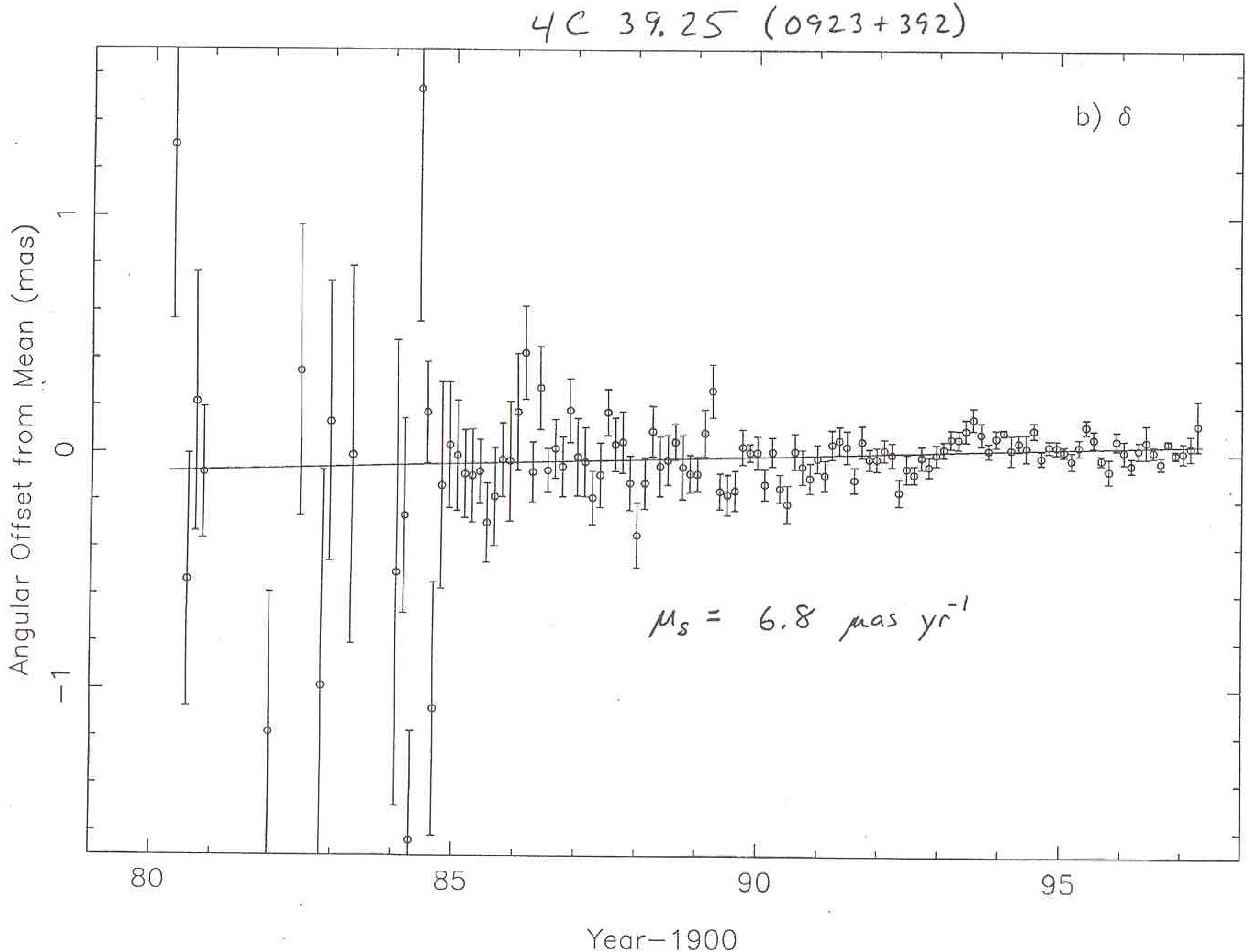
a) α cos δ
b) δ
Number of sources in error bin
100
80
60
40
20
0
0.5
1
1.5
2
Arc length error (mas)

The 294 ICRF Candidate Sources



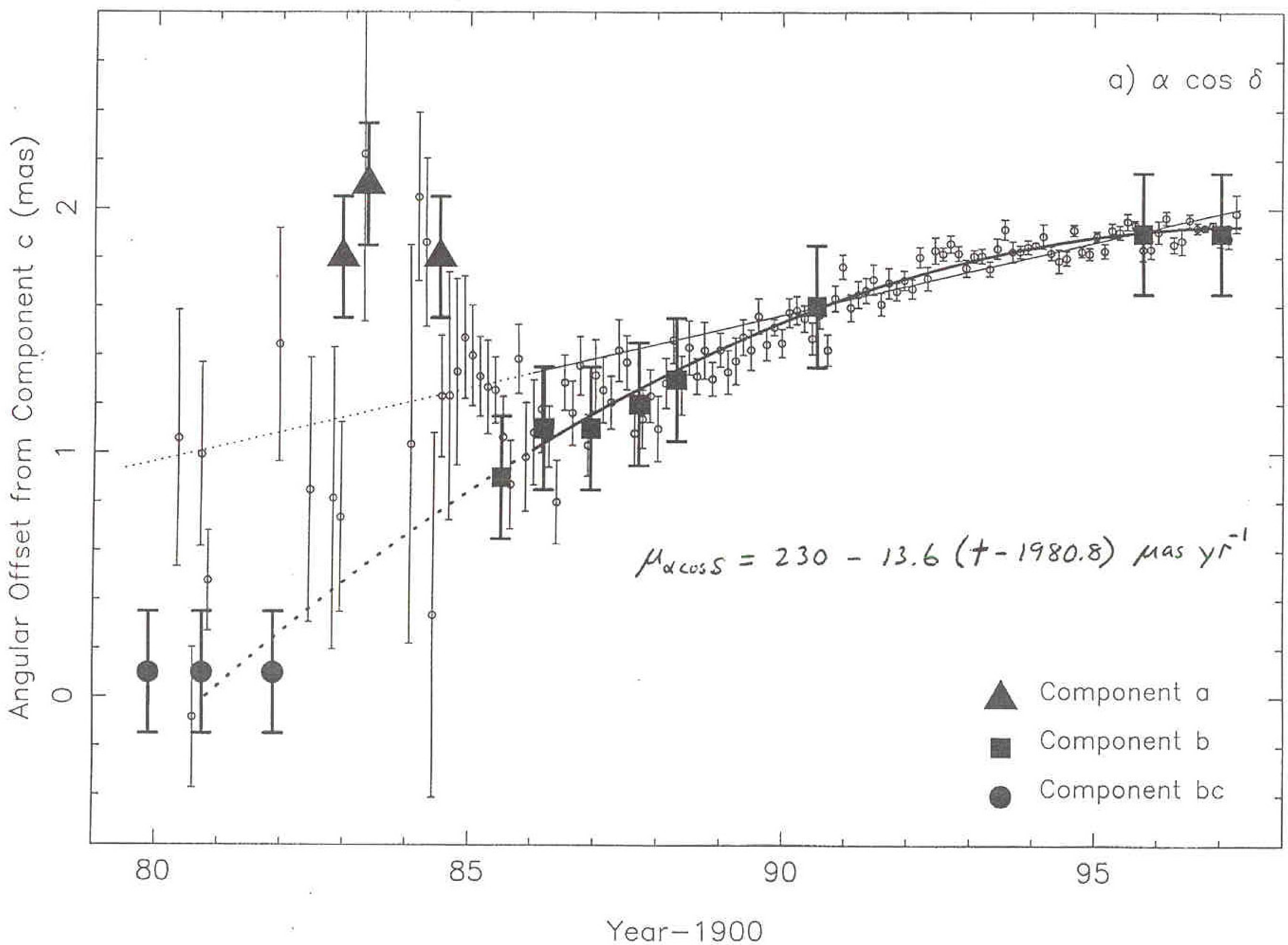


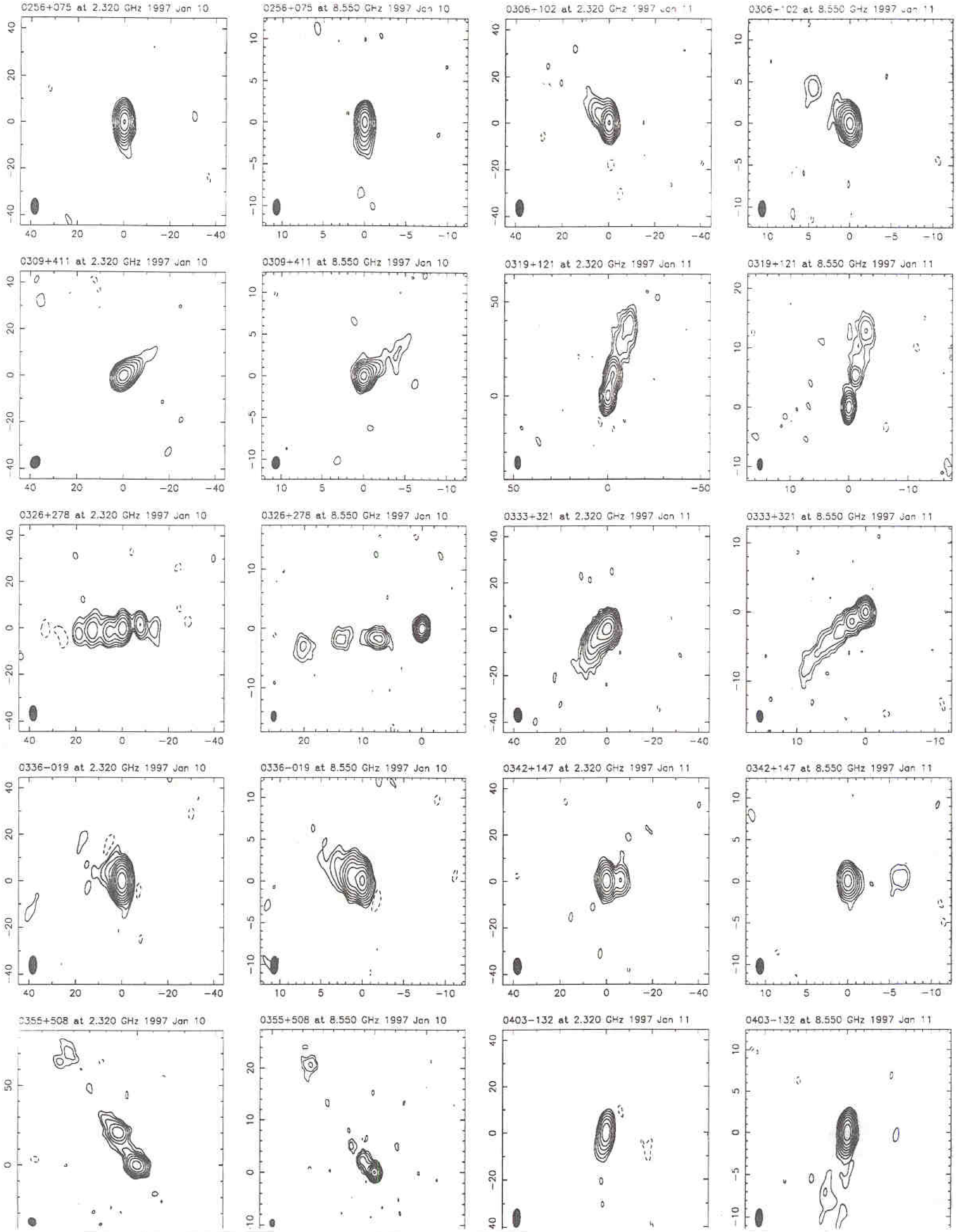
Guirado et al. 1995,AJ,110,2586



4C 39.25 (0923+392)
b) δ
μ_s = 6.8 mas yr^{-1}
Angular Offset from Mean (mas)
1
0
−1
80
85
90
95
Year−1900

4C 39.25 (0923+392)

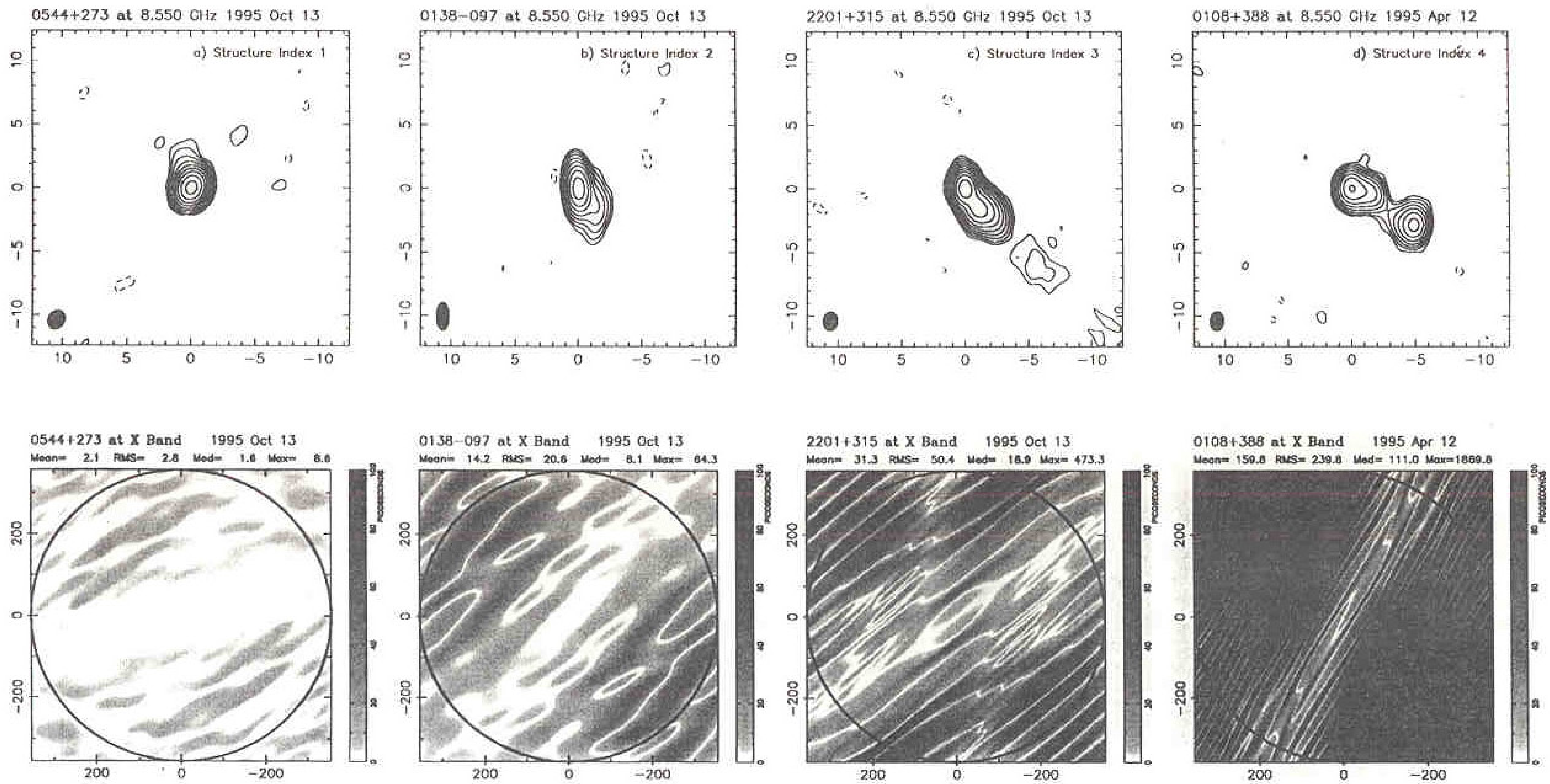




0256+075 at 2.320 GHz 1997 Jan 10
0256+075 at 8.550 GHz 1997 Jan 10
0306+102 at 2.320 GHz 1997 Jan 11
0306+102 at 8.550 GHz 1997 Jan 11
0309+411 at 2.320 GHz 1997 Jan 10
0309+411 at 8.550 GHz 1997 Jan 10
0319+121 at 2.320 GHz 1997 Jan 11
0319+121 at 8.550 GHz 1997 Jan 11
0326+278 at 2.320 GHz 1997 Jan 10
0326+278 at 8.550 GHz 1997 Jan 10
0333+321 at 2.320 GHz 1997 Jan 11
0333+321 at 8.550 GHz 1997 Jan 11
0336-019 at 2.320 GHz 1997 Jan 10
0336-019 at 8.550 GHz 1997 Jan 10
0342+147 at 2.320 GHz 1997 Jan 11
0342+147 at 8.550 GHz 1997 Jan 11
0355+508 at 2.320 GHz 1997 Jan 10
0355+508 at 8.550 GHz 1997 Jan 10
0403-132 at 2.320 GHz 1997 Jan 11
0403-132 at 8.550 GHz 1997 Jan 11

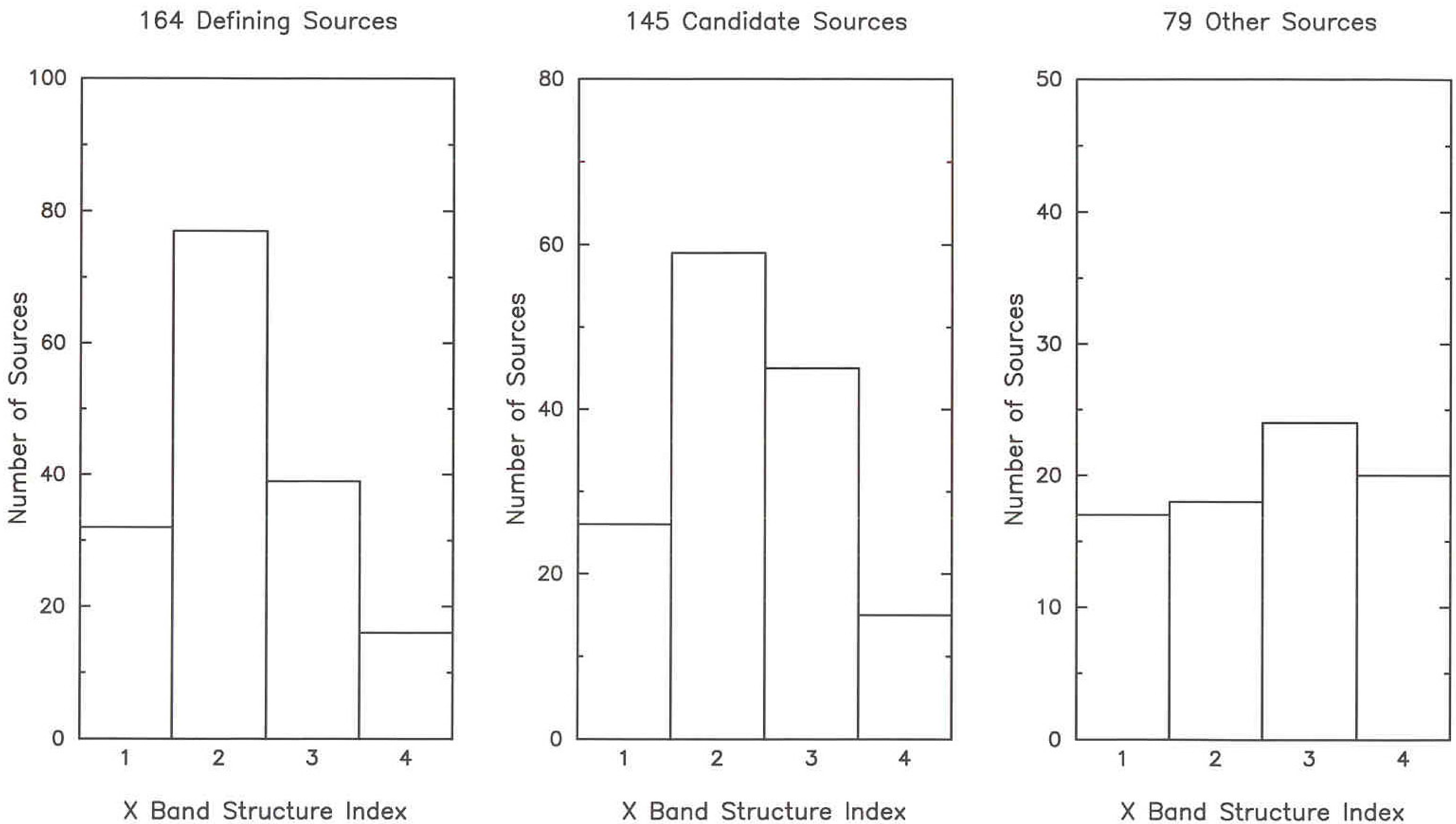
Structure Contribution to Measured Interferometric Delay

Top: Radio Emission at 3.6 cm Wavelength (Jy; mas)
Bottom: Structure Induced Bandwidth Synthesis Delay (ps; u,v)



Structure Classification of ICRF Sources

compact 1 2 3 4 extended



U.S. Naval Observatory **Earth Orientation Department**

The Radio Reference Frame Image Database (RRFID)

- **VLBA Images** -- `snapshot' images made using the **National Radio Astronomy Observatory** (NRAO) **Very Long Baseline Array** (VLBA) telescope. Images using the VLBA together with several geodetic antennas are also available for some sources. These 'VLBA+' images provide enhanced *uv*-plane coverage and up to twice the resolution of the VLBA alone. Available items include contour plots and visibility plots in PostScript format. Images and/or visibility data can also be obtained in FITS format upon request.

- **Geodetic VLBI Images** -- `snapshot' images made using geodetic and/or astrometric Very Long Baseline Interferometry (VLBI) observations. Available items include contour plots in PostScript format.

The data presented here are the result of an ongoing program to image the Radio Reference Frame sources on a regular basis. Our goal is to establish a database of images of all of the Radio Reference Frame sources at the same wavelengths as those used for precise astrometry (13cm and 4cm). These data will allow us primarily to monitor sources for variability or structural changes so they can be evaluated for continued suitability as Radio Reference Frame objects. Further information concerning these data can be found in the following publications:

- "VLBA Observations of Radio Reference Frame Sources. I.,"
  Astrophysical Journal Supplement Series, August 1996 issue (Vol. 105, No. 2, Pages 299-330).
- "VLBA Observations of Radio Reference Frame Sources. II. Astrometric Suitability Based on Observed Structure,"
  Astrophysical Journal Supplement Series, July 1997 issue (Vol. 111, No. 1, Pages 95-142).

If you make use of these data in any publication, please refer to the citation instructions.

VLA and VLBI images of many of these sources may also be obtained from the Pearson-Readhead and Caltech-Jodrell Surveys. See also the VLBA Calibrator Survey and the VLBA 2cm Survey.

Last modified: Wed Jan 14 14:26:38 EST 1998
Send comments on this page to afey@alf.usno.navy.mil.

Return to the Earth Orientation Department or go back to RORF, RRFID, or OID.

0005419

Netscape: RRFID VLBA Images Index

File Edit View Go Communicator Help

Back Forward Reload Home Search Netscape Print Security Stop

Bookmarks Location: ftp://rorf.usno.navy.mil/RRFID/index.html

USNO EO AD AB2 AAS CNNin NRAO AltaVista Lycos AJ

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The Radio Reference Frame Image Database
VLBA and VLBA+ Images

(This document is available with and without frames.)

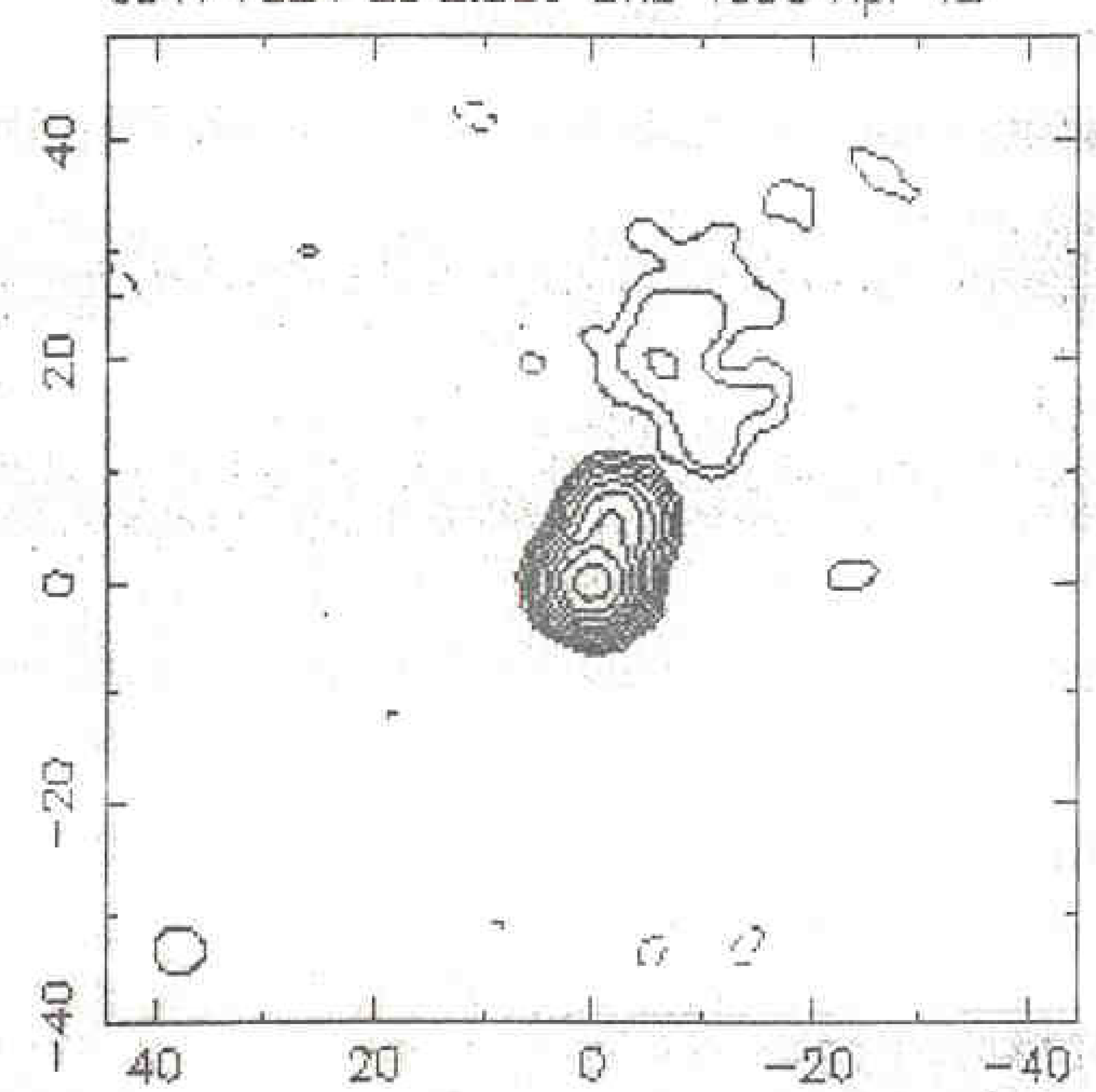
Available items include PostScript format contour plots of Radio Reference Frame source images at frequencies of **2 GHz**, **8 GHz**, and **15 GHz**. Plots of visibility data in PostScript format are also available. Calibration, data analysis, and other information can be obtained by retrieving the files CALIB.ps and README (one for each observation epoch). If you make use of these data in any publication, please refer to the citation instructions. Visibility data and images are available in FITS format upon request to afey@alf.usno.navy.mil.

Available Sources

0003+380, 0003-066, 0007+171, 0010+405,
0013-005, 0014+813, 0016+731, 0019+058,
0026+346, 0039+230, 0048-097, 0056-001,
0059+581, 0104-408, 0106+013, 0108+388,
0109+224, 0111+021, 0112-017, 0113-118,
0116+319, 0119+041, 0119+115, 0123+257,
0130-171, 0133+476, 0134+329, 0138-097,
0146+056, 0148+274, 0149+218, 0153+744,
0159+723, 0201+113, 0202+149, 0202+319,
0202-172, 0212+735, 0215+015, 0219+428,
0221+067, 0224+671, 0229+131, 0234+285,
0235+164, 0237+040, 0237-027, 0237-233,
0238-084, 0239+108, 0241+622, 0248+430,
0256+075, 0259+121, 0300+470, 0302+625,
0305+039, 0306+102, 0309+411, 0317+188,
0319+121, 0326+278, 0333+321, 0334+014,
0335-364, 0336-019, 0341+158, 0342+147,
0355+508, 0400+258, 0402-362, 0403-132,
0405+305, 0405-123, 0405-385, 0406+121,
0406-127, 0414-189, 0420+417, 0420-014,
0422+004, 0423+051, 0425+048, 0430+052,
0434-188, 0440+345, 0440-003, 0446+112,

The Image Database contains 2223 images of 426 sources.

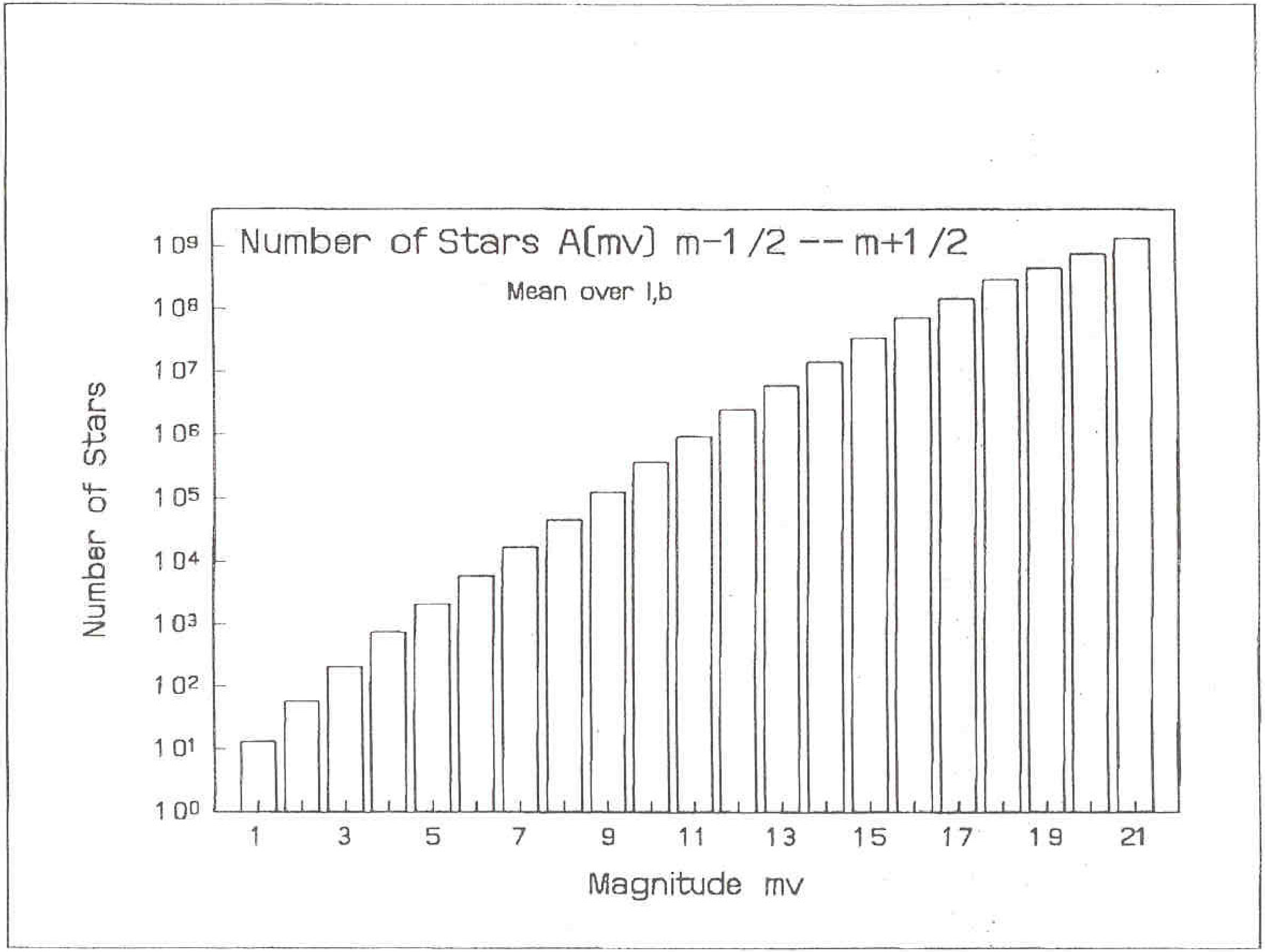
0917+624 at 2.320 GHz 1995 Apr 12



Hipparcos Catalog

- ✦118,217 stars distributed globally
- ✦Typical precession in position, parallax, and proper
  motion 1.5 mas
- ✦density ~ 2.7☆/sq.deg.
- ✦Epoch 1991.25

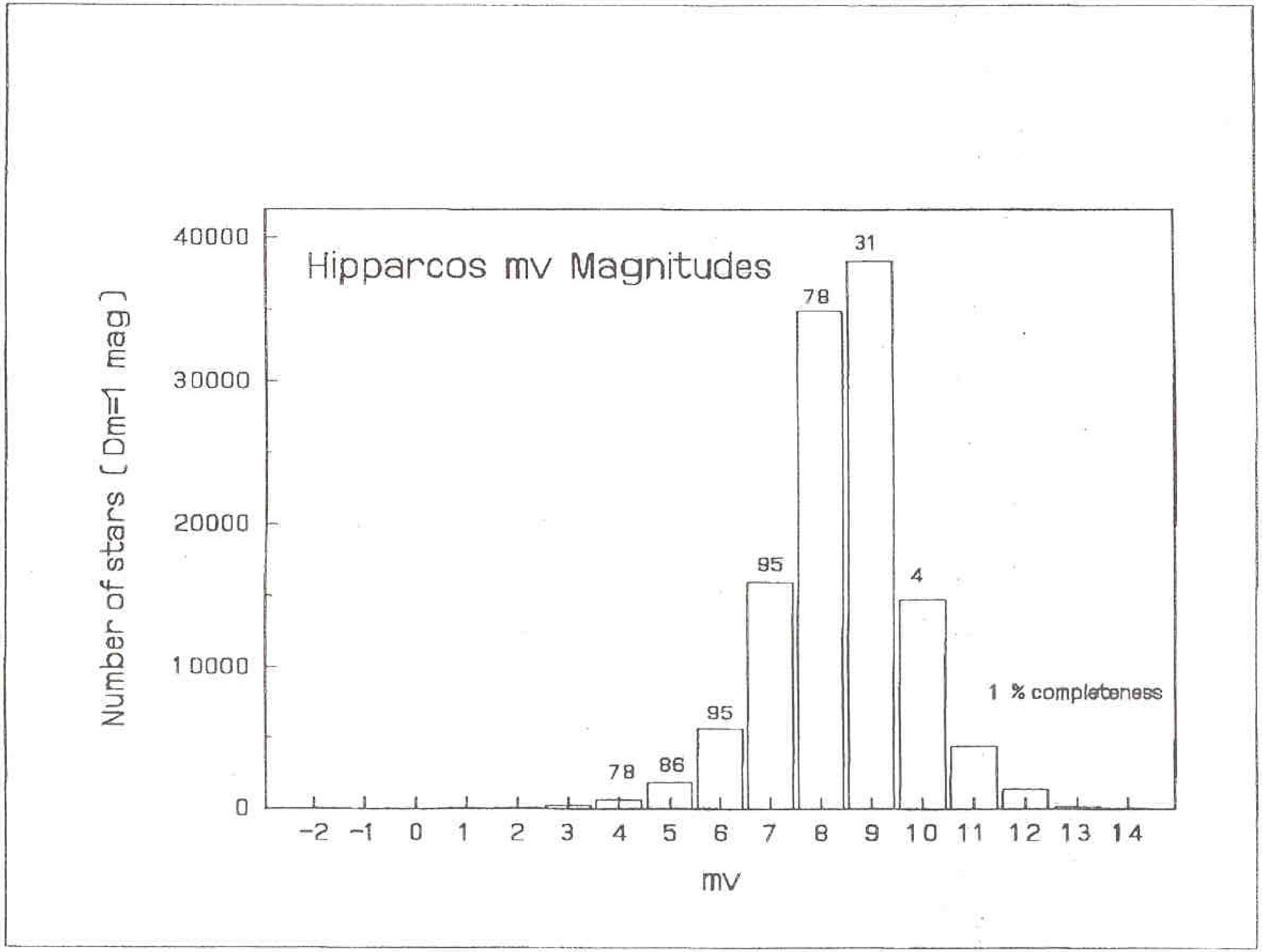
Fig 2



Number of Stars A(mv) m-1/2 -- m+1/2
Mean over l,b
Number of Stars
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1 3 5 7 9 11 13 15 17 19 21
Magnitude mv

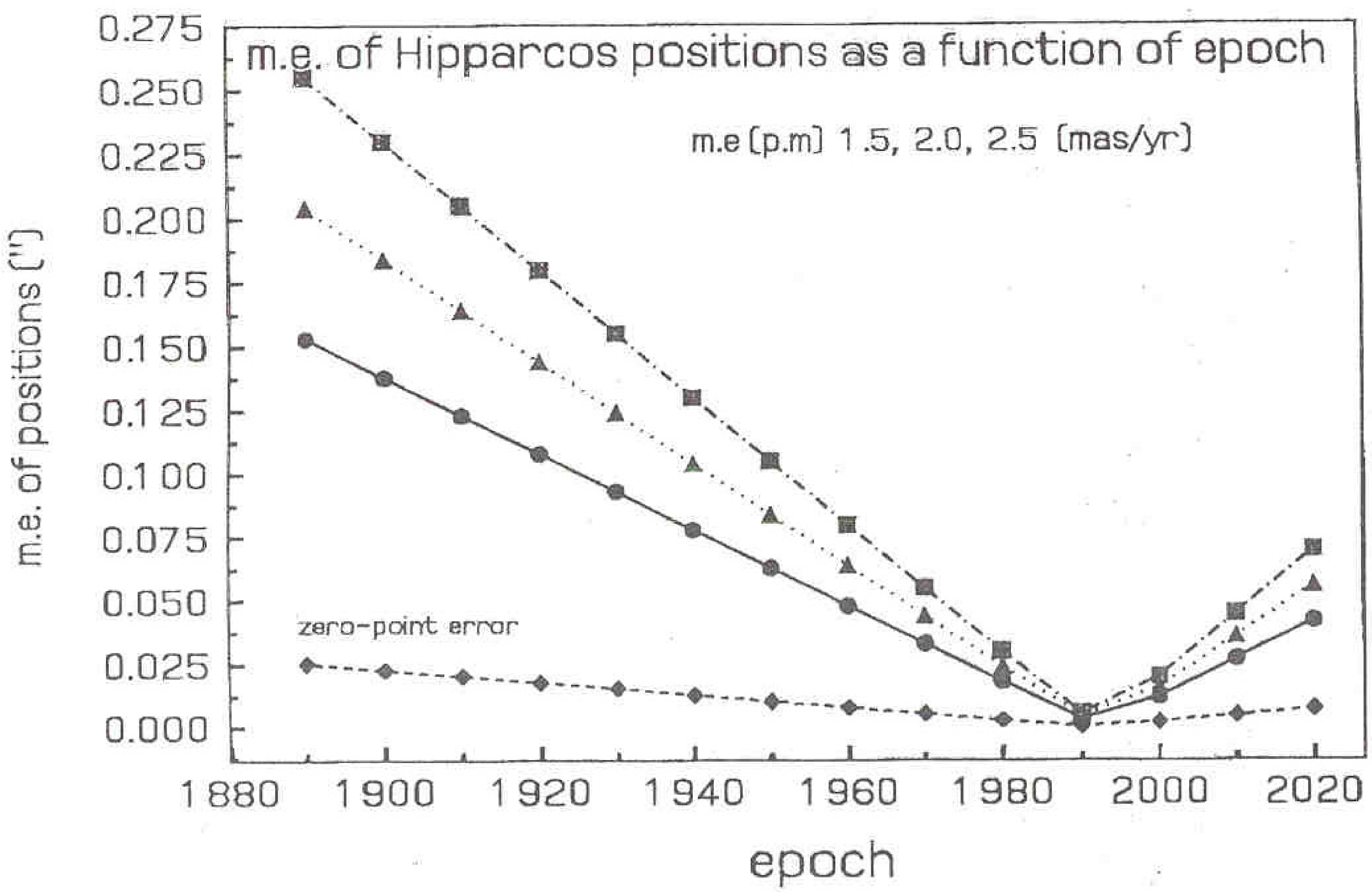
7

Fig 1


Hipparcos mv Magnitudes
Number of stars (Dm=1 mag)
40000
30000
20000
10000
0
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
mv
78
86
95
95
78
31
4
1 % completeness

10

Fig 4



m.e. of Hipparcos positions as a function of epoch
m.e (p.m) 1.5, 2.0, 2.5 (mas/yr)
zero-point error
m.e. of positions ('')
epoch
0.275
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
1880
1900
1920
1940
1960
1980
2000
2020

ICRF/Hipparcos Link

Offset	± 0.6 mas	Epoch
rotation	± 0.25 mas/yr	1991.25

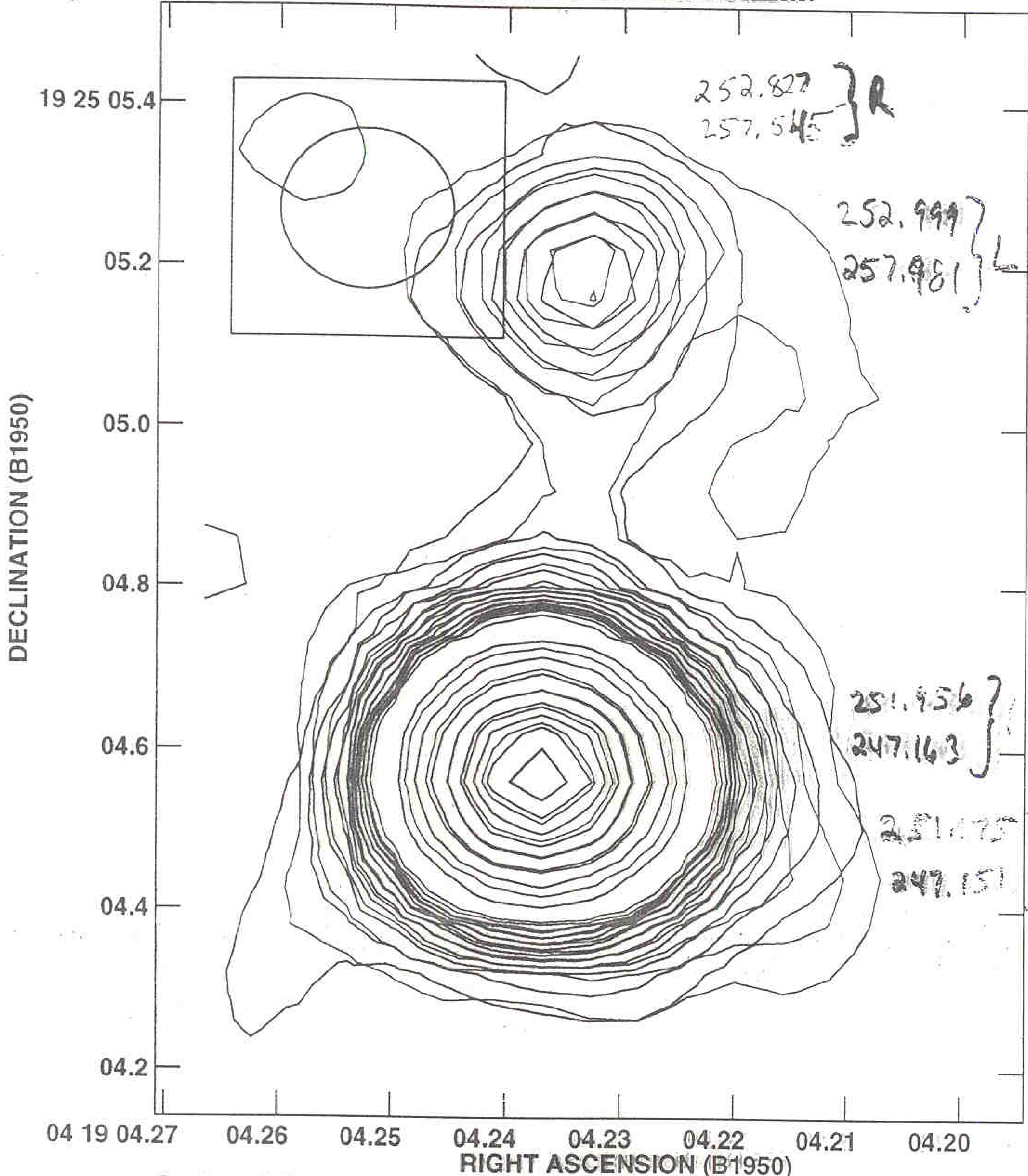
Dominated by 13 radio stars via VLBI.

Four dominant stars

Star	Pos. mas	P.M. mas/yr	Par
Algol	0.61	0.18	0.59
HR1099	0.48	0.31	0.47
∇^{2}CrB	0.29	0.05	0.10
ARLac	0.94	0.19	0.73

Present offset 1998.8 > 5mas

PLot file version 2 created 07-FEB-1997 14:10:20
CONT: TTAU BR 84114.900 MHZ 88TTAU X.RCLN.1



Cont peak flux = 9.3884E-03 JY/BEAM
Levs = 9.3884E-05 * (1.000, 2.000, 3.000,
4.000, 5.000, 6.000, 7.000, 8.000, 9.000,
10.00, 20.00, 30.00, 40.00, 50.00, 60.00,
70.00, 80.00, 90.00)

T Tau N

Optical (Hipparcos) - Radio Positions at the Epoch of the Radio Measurements

JEP	△ RA mas	△ Dec mas
83.7084	-2	-3
86.2546	-16	-4
88.8282	+2	-6
89.0910	+0	+0
92.8830	+6	+0
95.5305	+31	-5

Differences at central VLA epochs

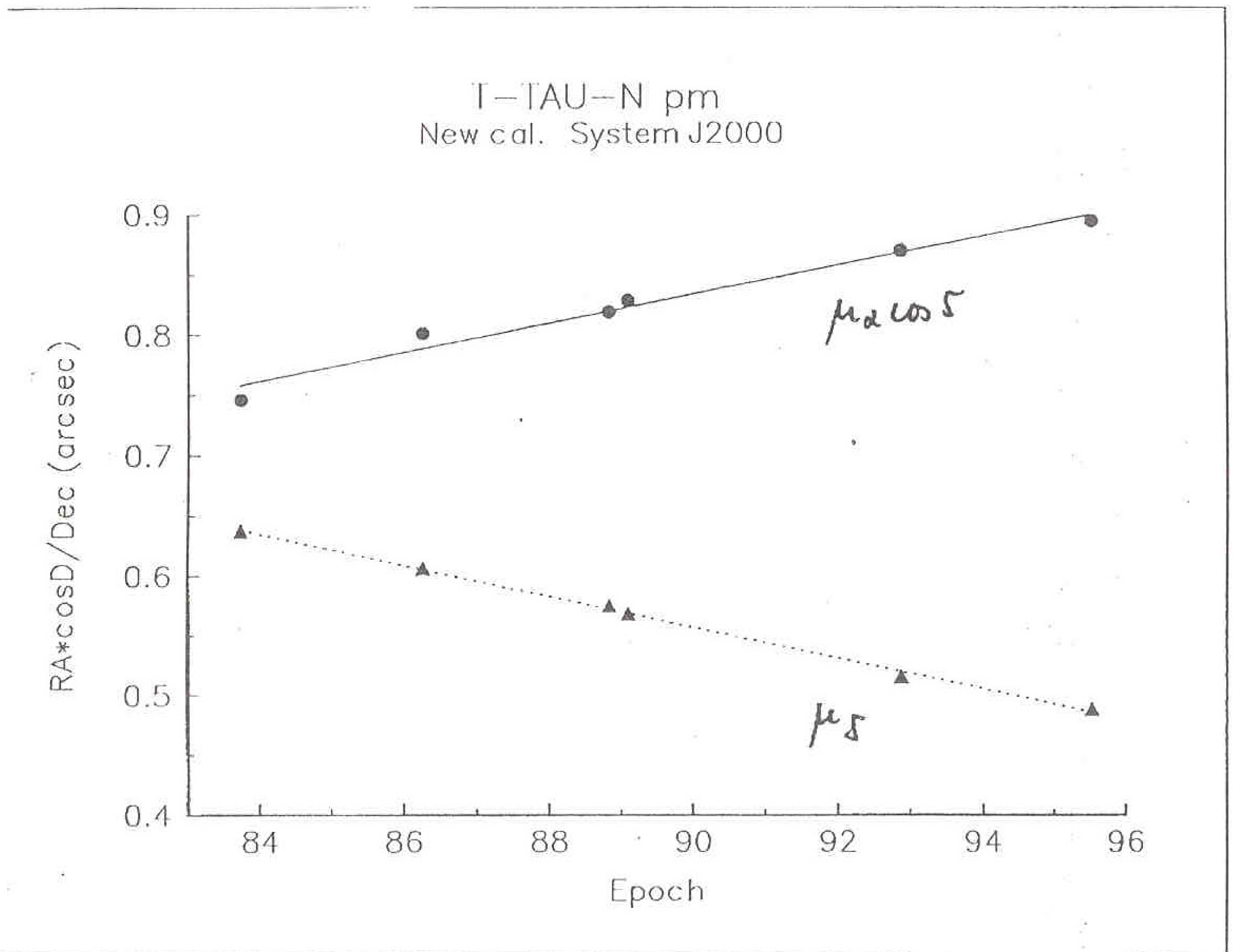
△ RA = 1.07+ - 4.54 mas

△ Dec = -1.16+ - 4.43 mas

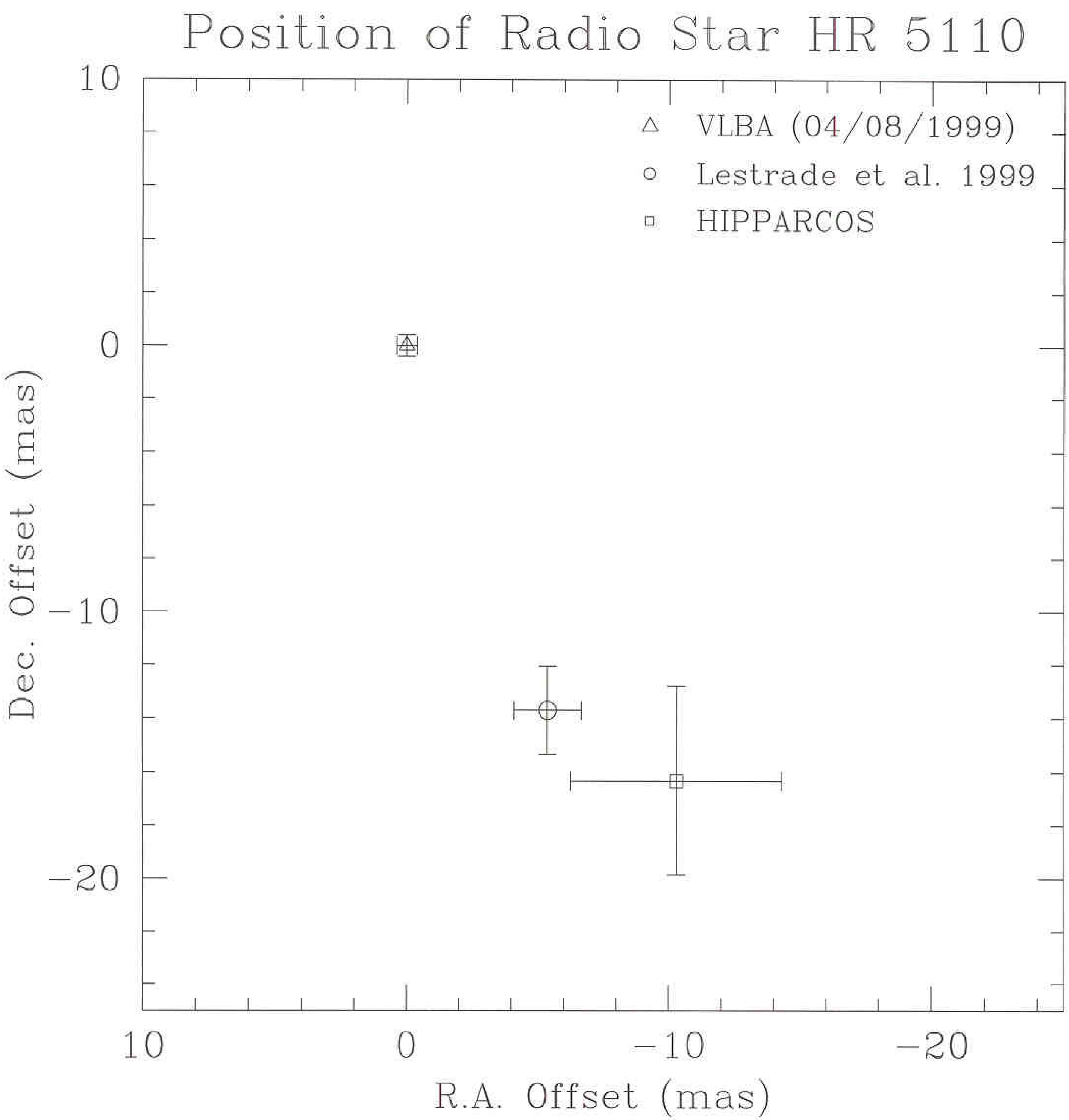
Proper Motions

(mas)

	$\mu\alpha$	$\mu\delta$
Radio	12.33 ± 1.00	-13.28 ± 0.86
Optical (Hipparcos)	15.45 ± 1.88	-12.48 ± 1.62



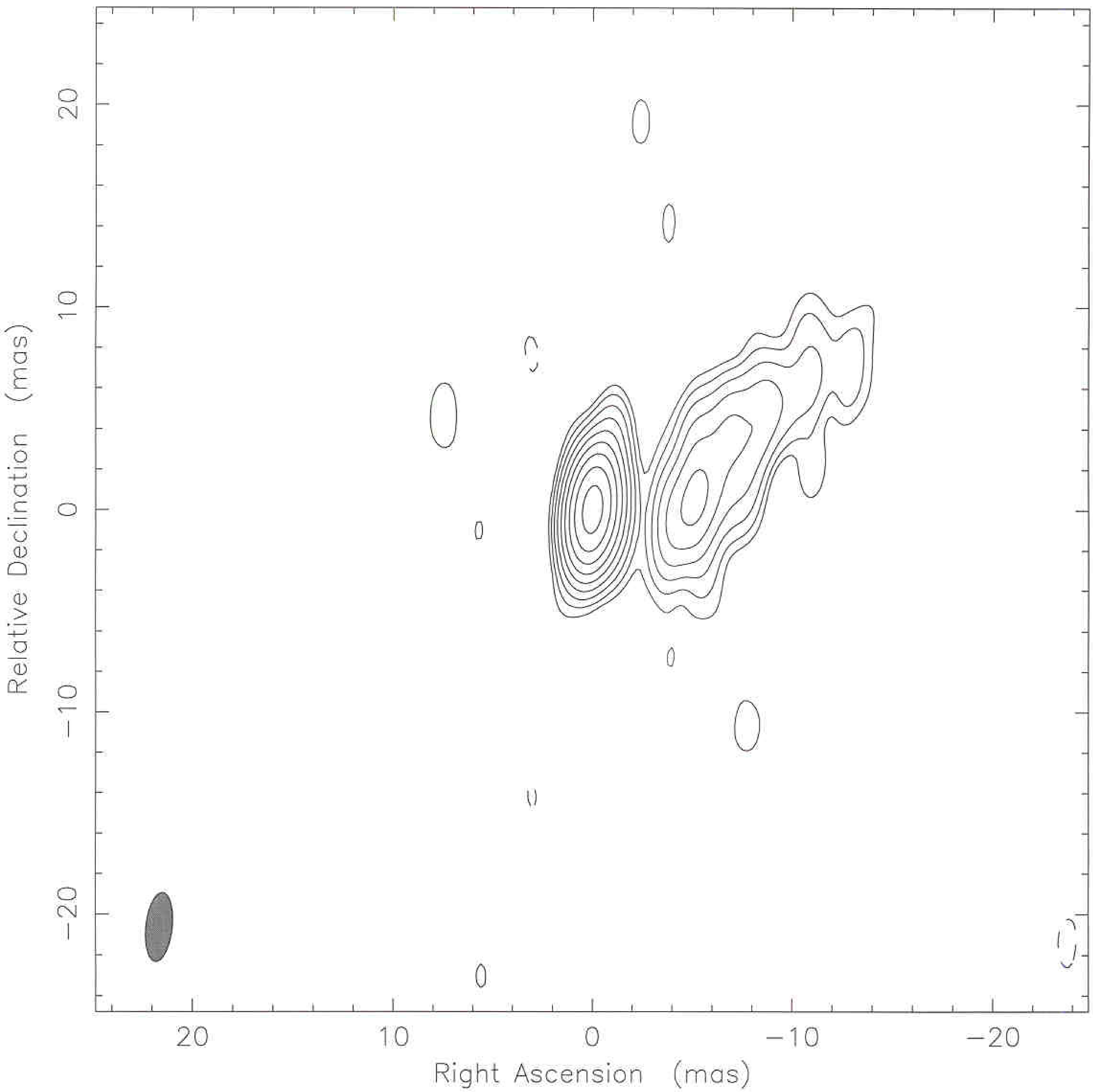
061-202-762-14


Position of Radio Star HR 5110
VLBA (04/08/1999)
Lestrade et al. 1999
HIPPARCOS
Dec. Offset (mas)
R.A. Offset (mas)
10
0
−10
−20
10
0
−10
−20

Limitations

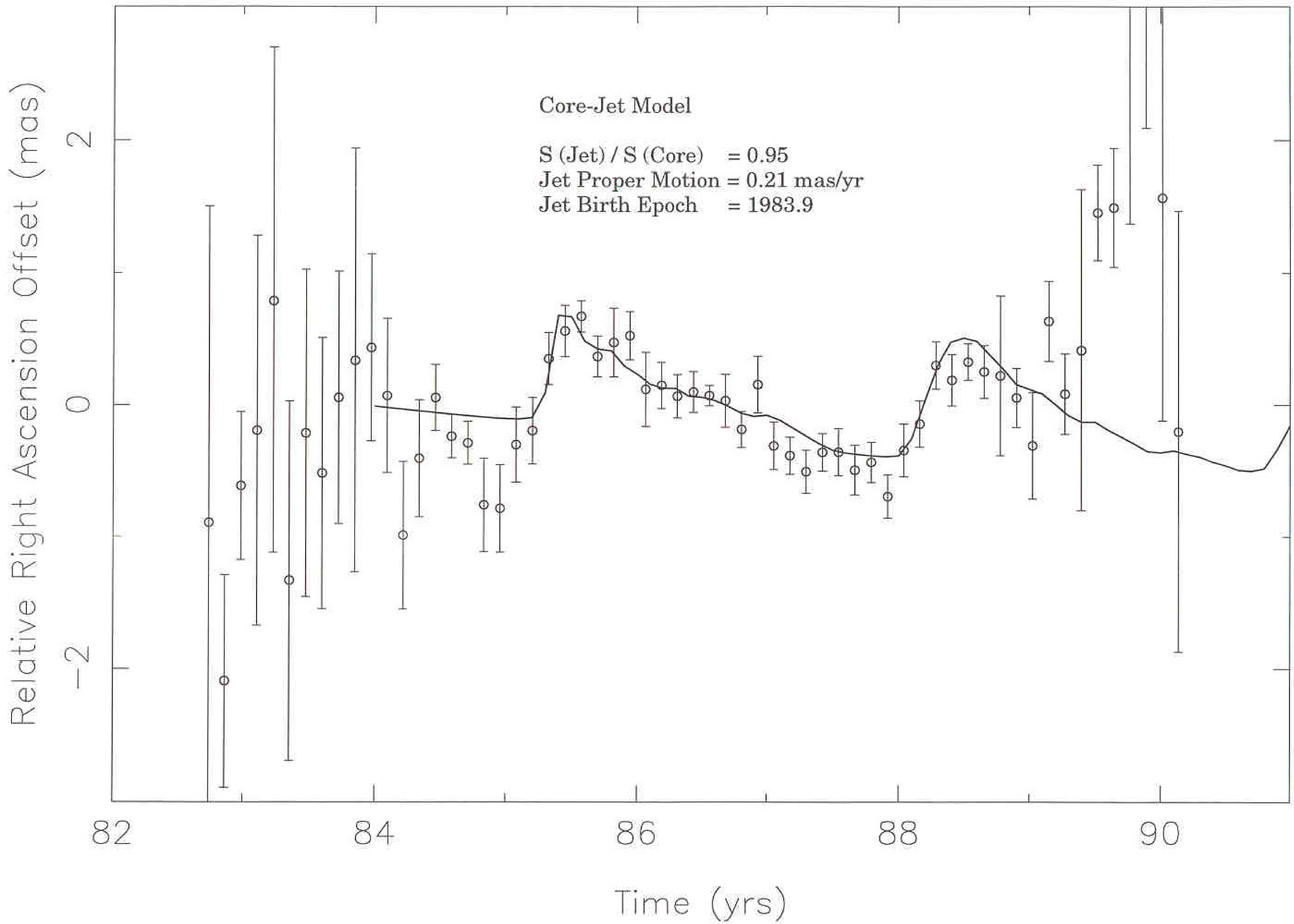
- Reference sources
  - → structure
  - → motions
- Instrumental
  - → baseline geometry
  - → thermal
- Environment
  - → ground
  - → space

Clean map. Array: BFHKLMOPS
2251+158 at 4.987 GHz 1997 Jan 12



Map center: RA: 22 53 57.748, Dec: +16 08 53.563 (2000.0)
Map peak: 6.97 Jy/beam
Contours: 0.0195 Jy/beam x (−1 1 2 4 8 16 32 64
Contours: 128 256)
Beam FWHM: 3.4 x 1.31 (mas) at −6.58°

3C 454.3 (2251+158)



Future Accuracy

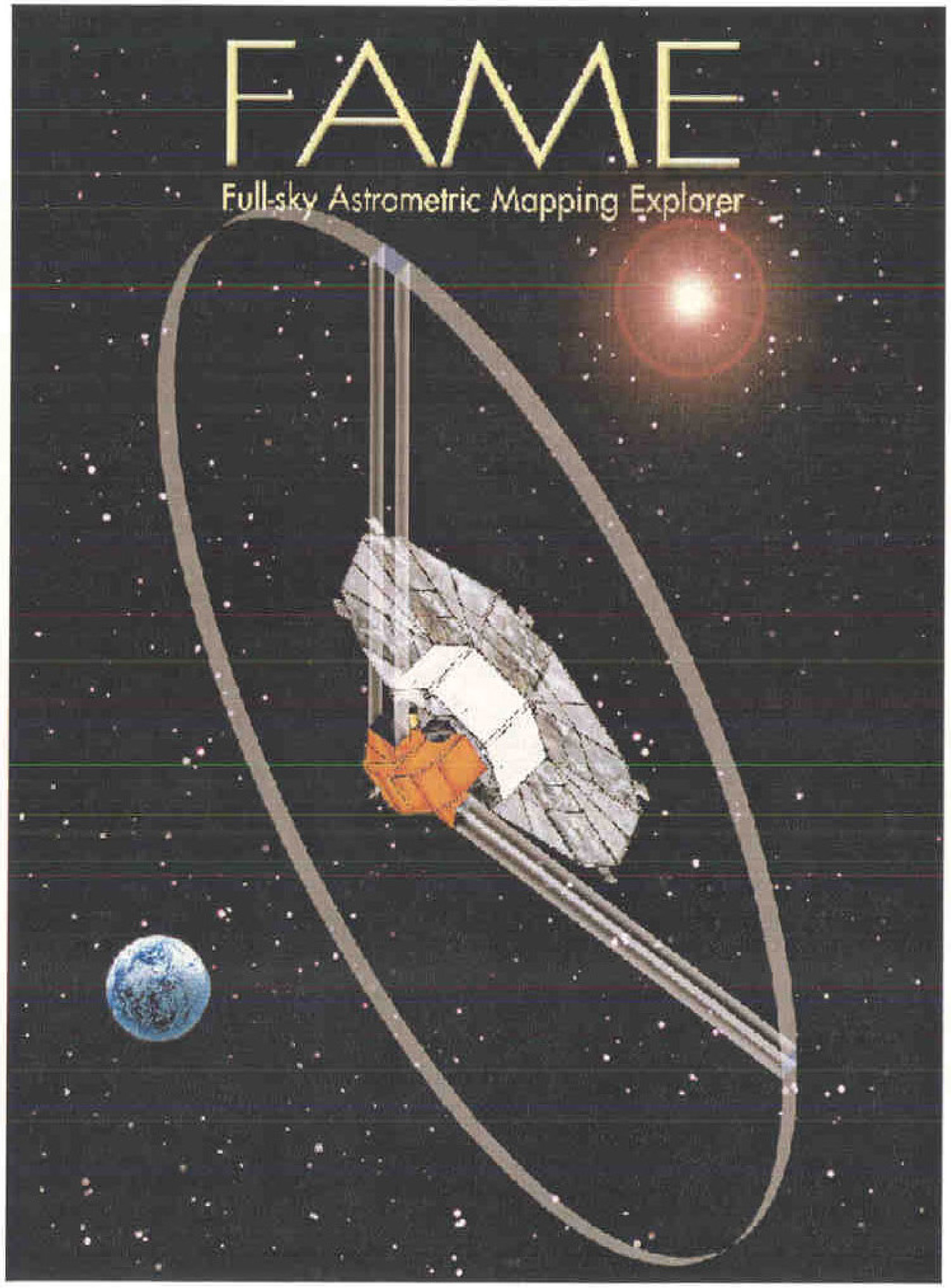
- Optical: 4-10 μas

FAME	50 μas	2,000,000
SIM	4 μas	4,000 source
GAIA	10 μas	

- Radio: 10-15 μas

  Eliminate source structure effects.

  Future space array
- IR: 10 mas?
- Xray: ?



***F**ull-sky*
***A**strometric*
***M**apping*
***E**xplorer*

http://www.usno.navy.mil/fame

Full-sky Astrometric Mapping Explorer

- Small satellite to perform an all sky, astrometric survey with unprecedented accuracy
  - Upgrades existing star catalogs by providing a precision catalog of 4×10^7 Stars
  - Provides positions of all bright stars ($5 < m_v < 9$) to $< 50 \mu as$
  - Provides positions of fainter stars ($9 < m_v < 15$) to $< 500 \mu as$
  - 2.5 year mission allows for accurate measurement of stellar parallax and proper motions
  - Photometric data in four Sloan DSS bands (g', r', i', z')

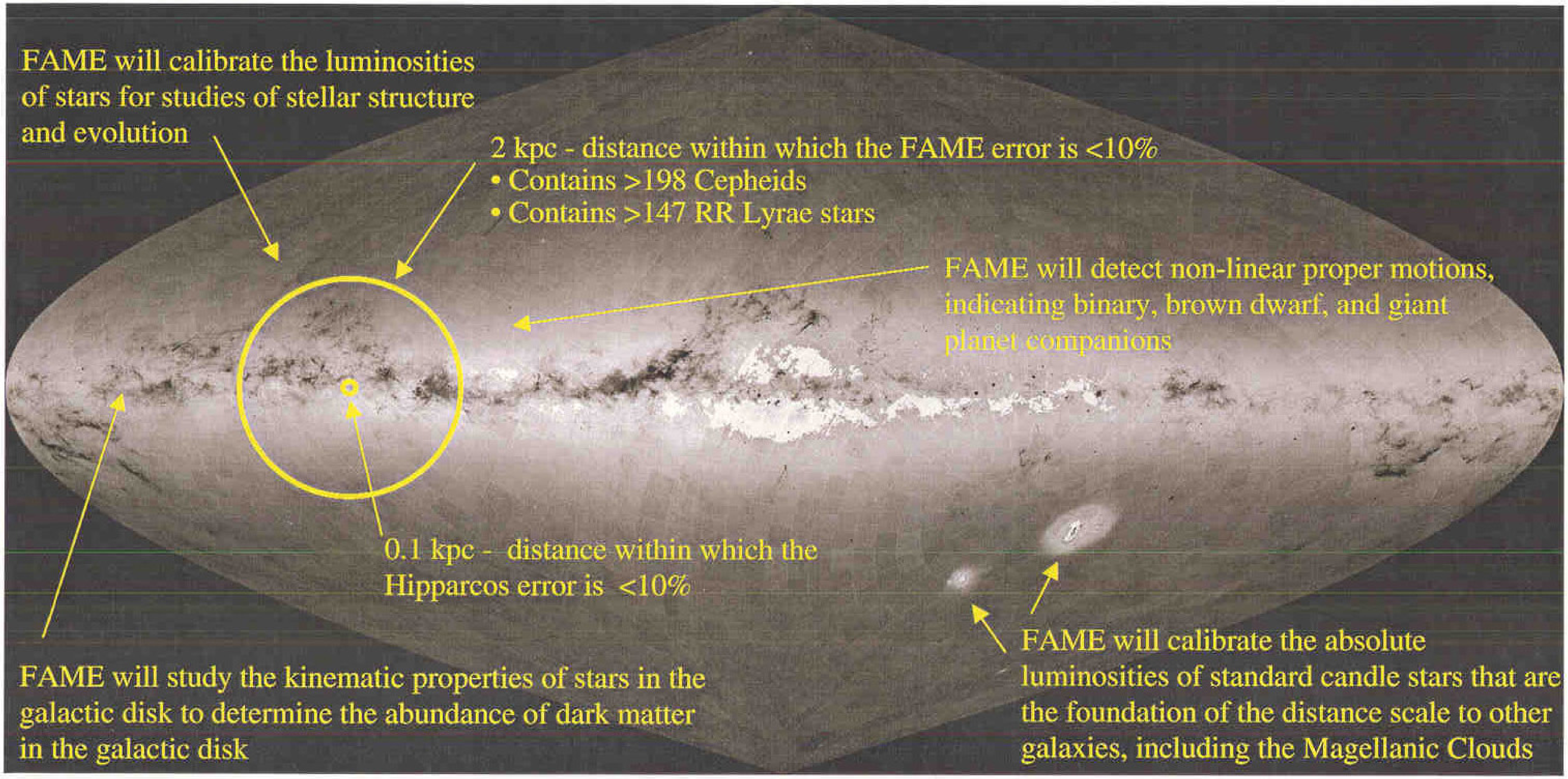
Full-sky Astrometric Mapping Explorer

- Measure the positions, parallaxes, and four-color magnitudes of 40 million stars brighter than 15th visual magnitude
- Measure with 10% error or better the absolute trigonometric parallaxes of stars brighter than 9th visual magnitude within 2 kpc of the Sun
- Measure the positions, trigonometric parallaxes, and proper motions of all stars out to 15th visual magnitude with accuracies of:

  50 μas at 9th visual magnitude

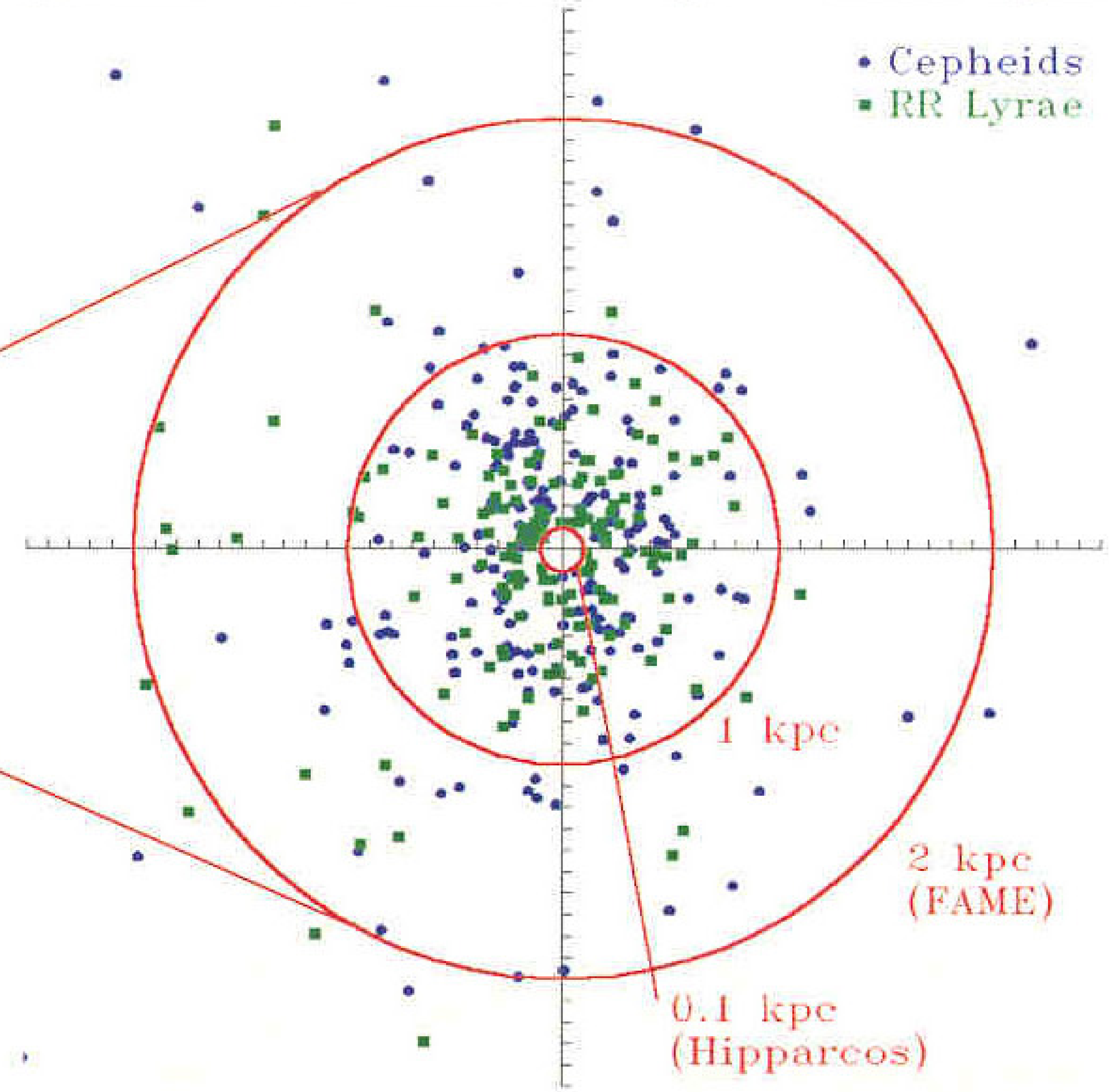
  500 μas at 15th visual magnitude

FAME Coverage of the Milky Way



FAME Science - FAME will map our quadrant of the galaxy out to 2 kpc from the Sun providing the information needed to calibrate the standard candles that define the extragalactic distance scale, calibrate the absolute luminosities of stars of all spectral types for studies of stellar structure and evolution, and detect orbital motions caused by brown dwarfs and giant planets. FAME will not only improve on the accuracies of star positions determined by Hipparcos but also expand the volume of space for which accurate positions are known by a factor of 8,000.

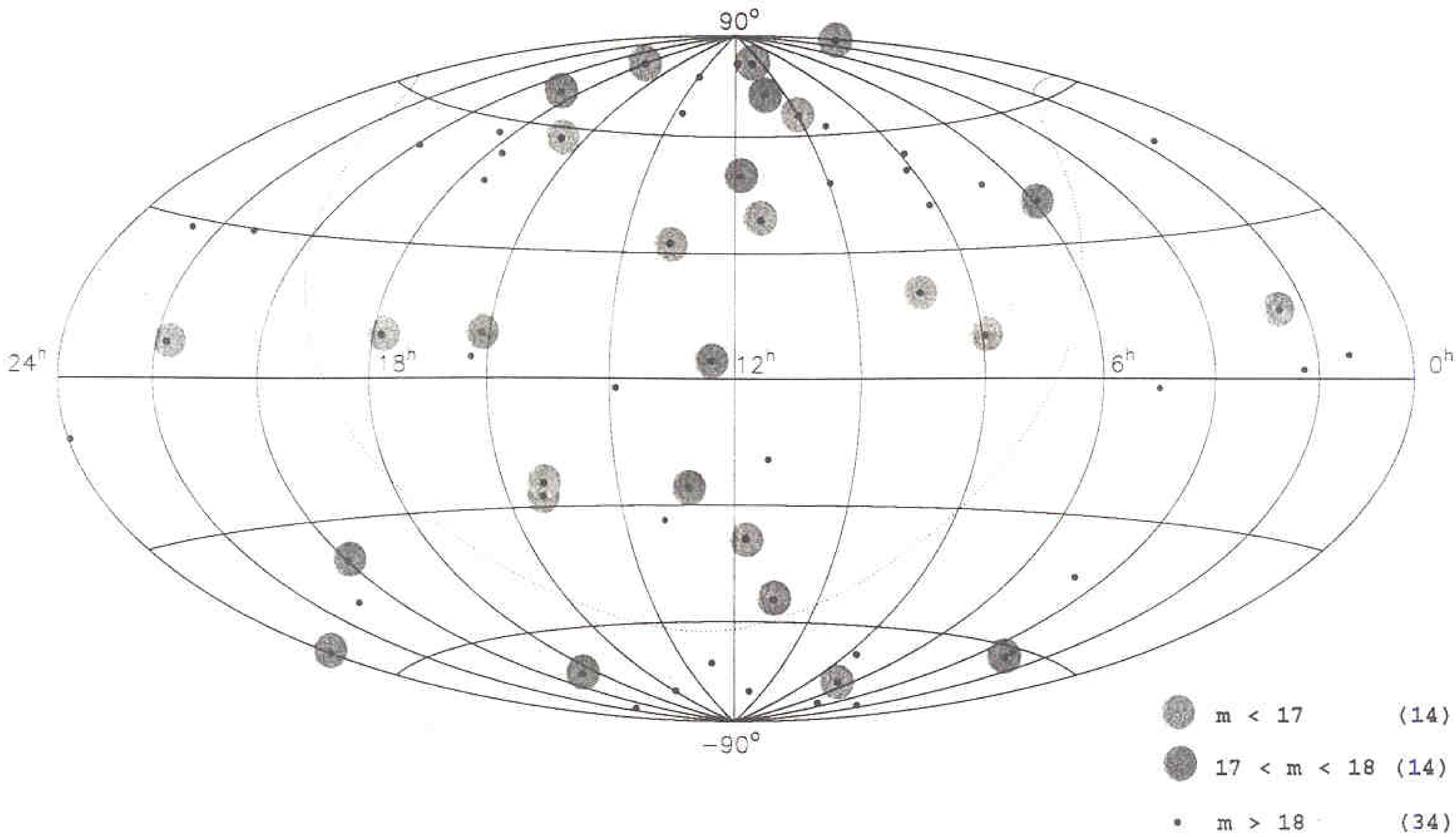
FAME Coverage of the Milky-Way



ICRF

- **Present**
  - → **Based on 212 extragalactic radio sources**
- **Future**
  - → **Use common sources**

Best Radio Astrometric Sources



Visual Magnitude	SIM Integration Time per source (min)	No. Sources
14 < m < 15	1 < t < 3	2
15 < m < 16	3 < t < 7	4
16 < m < 17	7 < t < 17	8
17 < m < 18	17 < t < 43	14
18 < m < 19	43 < t < 109	20
19 < m < 20	109 < t < 275	13
m > 20	t > 275	1

6
28 5
136
420

14
301
420

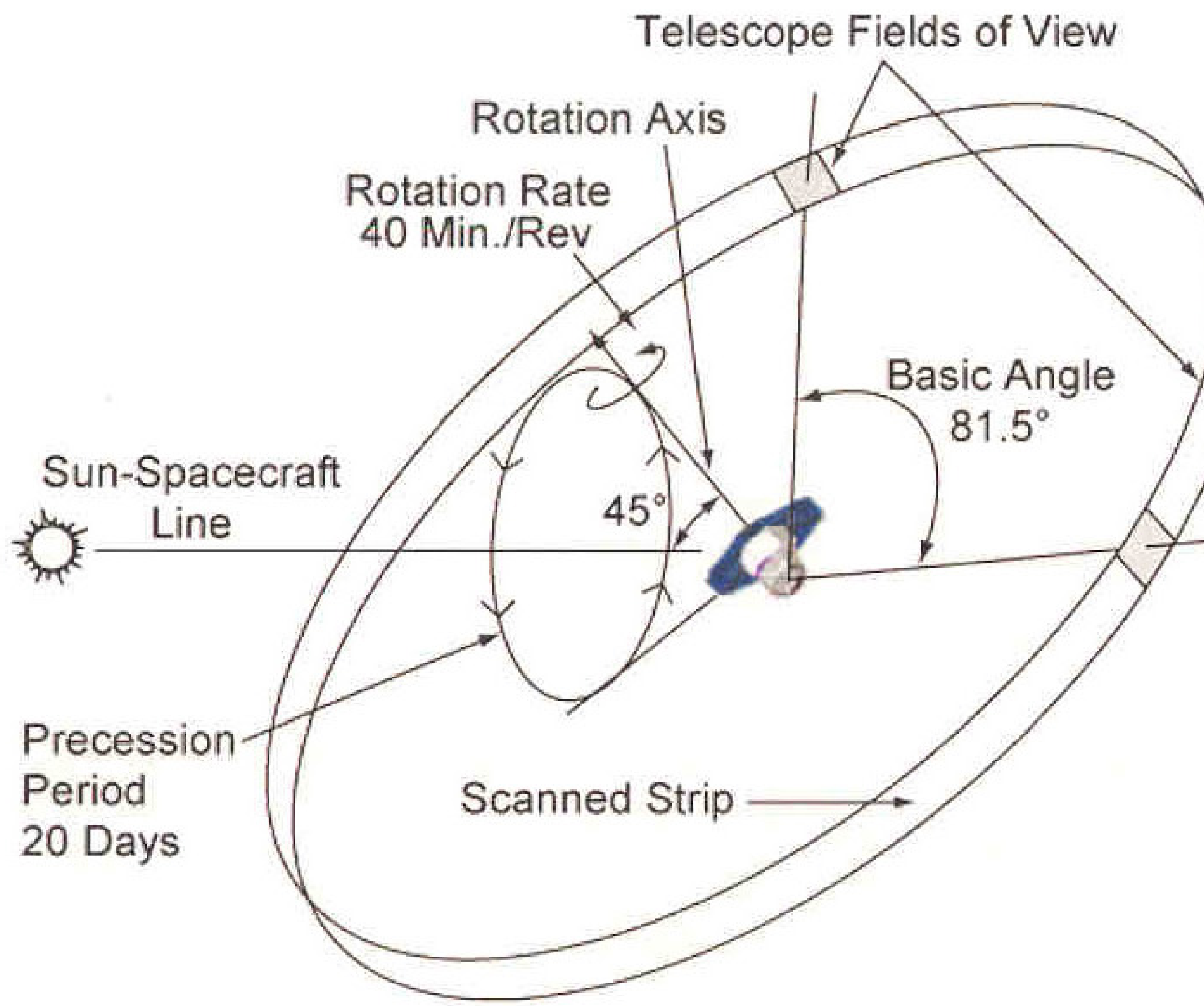
6
15
45
420
506 MIN
60
7 hrs

Full-sky Astrometric Mapping Explorer

- One of five NASA Medium-Class Explorers (MIDEX) selected for a concept study (just completed)
- Two of these five missions will be selected for flight; selection is scheduled for September
- Joint development effort of:
  - United States Naval Observatory
  - Naval Research Laboratory
  - Lockheed Martin Missiles and Space
  - Smithsonian Astrophysical Observatory

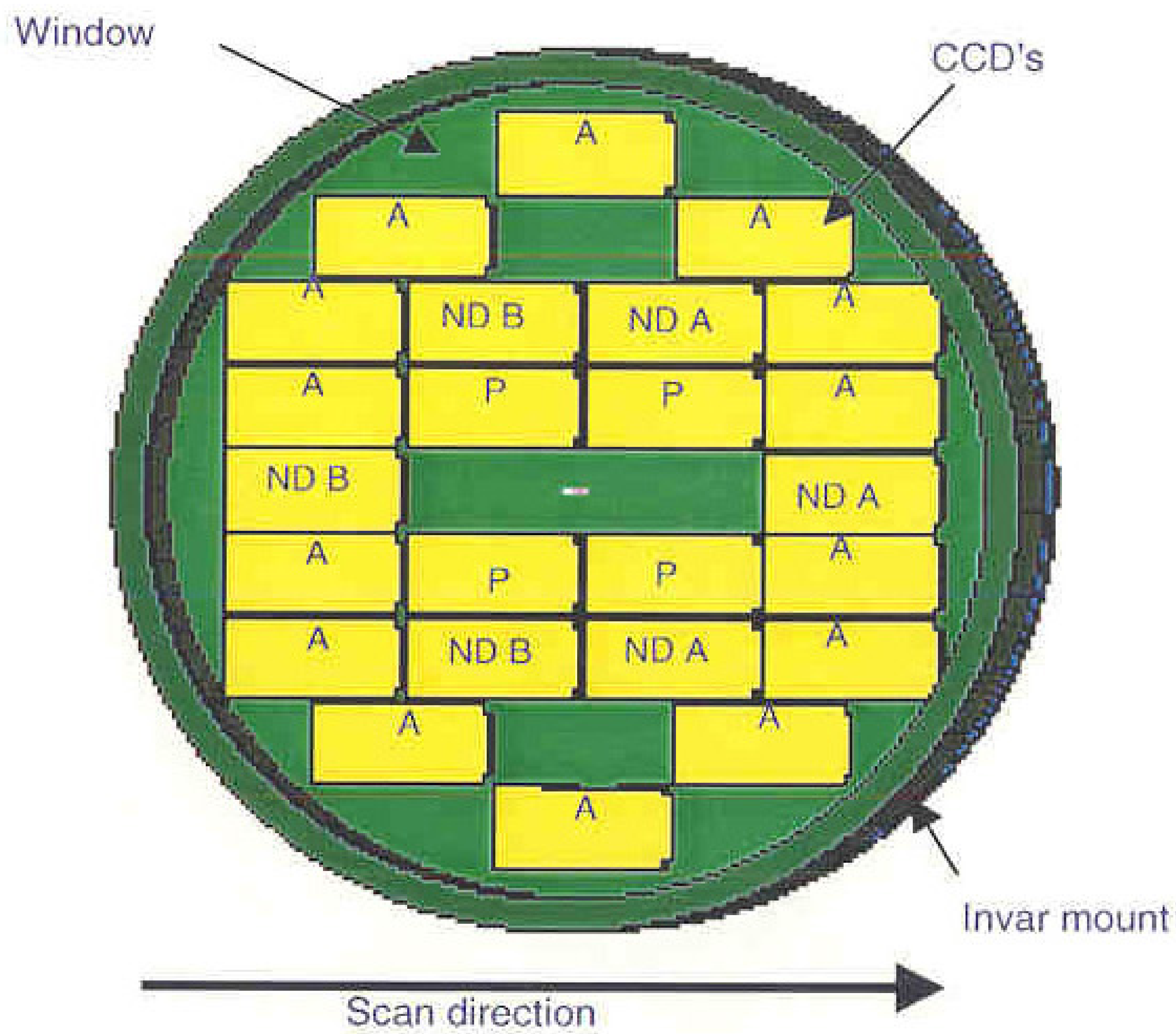
FAME Mission Description

- The telescope has two fields-of-view separated by a 81.5° basic angle
- The spacecraft will rotate with a 40 minute period with the apertures sweeping out a great circle on the sky
- The spacecraft rotation axis is at a 45° angle to the Sun
- The solar radiation pressure on the solar shield results in precession about the Sun-spacecraft line with a 20 day period



The FAME observing concept - The axis of the FAME spacecraft is pointed 45° from the Sun and precesses around the Sun with a 20 day period. The FAME spacecraft rotates with a 40 minute period. The two fields of view are normal to the rotation axis and are separated by a 81.5° degree basic angle.

FAME Instrument Description



The FAME focal plane - 24 2k·4k CCDs arranged around a 1.1° diameter field of view. Devices marked with 'P' are the 4 photometric CCDs and devices marked with 'A' are the 20 astrometric CCDs. The 6 devices marked with 'ND' have neutral density filters for astrometry of brighter stars.

- **Telescope produces images of Stars using 24 large format CCDs**
  - **Images of stars are continually traversing CCD array as the spacecraft rotates**
  - **CCDs use time delay integration**
  - **Synchronization of CCD clock rate and image motion is assured via rotation rate sensors**
  - **Star images are time tagged, windowed, and transmitted to Earth.**
  - **6 CCDs are covered by neutral density filters for astrometry of bright stars**

FAME Error Sources

CCD characteristics

- read noise
- dark current
- non-linearity
- charge transfer inefficiency
- deterioration of CTE from radiation damage
- variations in the CCD flatness
- pixel-to-pixel gain variations
- sub-pixel gain variations
- wavelength dependent gain variations
- CCD defects
- CCD pixel registration errors
- color dependent penetration of photons
- recovery from saturation
- CCD clock cross-talk
- CTE behind bright stars
- ADC errors

FAME Error Sources

(continued)

- **Instrument alignment**
  - **point-spread function (PSF)**
  - **PSF variations with position in field**
  - **misalignment of the CCD column with the rotation**
  - **variation of plate scale across field**
- **Instrument stability**
  - **PSF variations with time**
    - **errors in CCD clock rate relative to rotation**
    - **error in determination of rotation rate**
    - **error in setting the clock speed**
  - **Variations in telescope structure**
    - **thermal**
    - **evaporation**
  - **Variation in basic angle**

FAME Error Sources

(continued)

- Photon statistics
- Spacecraft
  - CCD/window contamination
  - aberration due to error in knowledge of S/C velocity
- Stellar/External
  - saturation
  - stellar activity
  - stellar companions
  - incorrect stellar model
  - confusion
  - cosmic rays
  - scattered light

Fame Error Sources

- CCD characteristics
  - Read noise, QE variation, etc.
- Instrument alignment
  - PSF variations
- Instrument stability
  - Thermal effects
- Spacecraft
  - Knowledge of spacecraft velocity
- Stellar/external
  - Photon statistics

FAME Estimated Error Budget Totals

Visual Magnitude (m_V)	ND Filter Accuracy* (μas)	Gated Array Accuracy* (μas)
5	29	14
7	48	14
9	15	14
11	30	28
13	76	70
15	226	208

*Assumes systematic error contribution is 10 μas

The FAME accuracy - The predicted accuracy of FAME as a function of visual magnitude (m_v). The second column shows the accuracy if neutral density filters over 3 of the astrometric CCDs are used for astrometry of the brighter stars (baseline design). The third column shows the accuracy if the CCDs are only integrating during part of the time when a bright star is traversing the device (alternate design).

FAME Technology Challenges

- Centroiding accuracy of CCD in time delay integration to 1/700 pixel
- Solar radiation attitude control without thrusters
- Thermal stability of 1 mK for optical bench
- Communications link to support data downlink of 400 kbps continuous
- Microarcsecond astrometric data reduction to model all effects including aberration, relativistic effects, geodesic precession, and nutation

FAME Technology Challenges

(continued)

- Large number of large format CCDs in the radiation environment at geosynchronous orbit
- Data solution for 40,000,000 stars with 4000 observations each for position, parallax, proper motion, and non-linear motions
- Total astrometric errors at 15 microarcseconds before photon statistics
- Optimum readout, on board processing, storing, tagging of data, transmission, and solutions

FAME Schedule

Phase A Concept Study	February - June 1999
Phase B	October 1999 - June 2000
Phase C	July 2000 - March 2001
Phase D	April 2001 - June 2003
Launch	July 2003
Phase E	July 2003 - January 2007
Possible DoD extended mission	January 2006 - July 2009

Summary

- FAME has been selected by NASA for a MIDEX Phase A Concept Study (one of five missions selected). In September 1999, NASA will select 2 MIDEX missions for flight
- Recalibrates the extragalactic distance scale
- Determines absolute luminosities of a wide range of spectral types
- Detects companion stars, brown dwarfs, and giant planets
- Enables studies of the kinematics of our galaxy
- Defines an optical reference frame for future scientific and military endeavors